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FINAL REPORT

STUDY OF THE AUTOMATED BIOLOGICAL LABORATORY PROJECT DEFINITION

VOLUME II OF VI SCIENTIFIC PAYLOAD DEFINITION STUDIES

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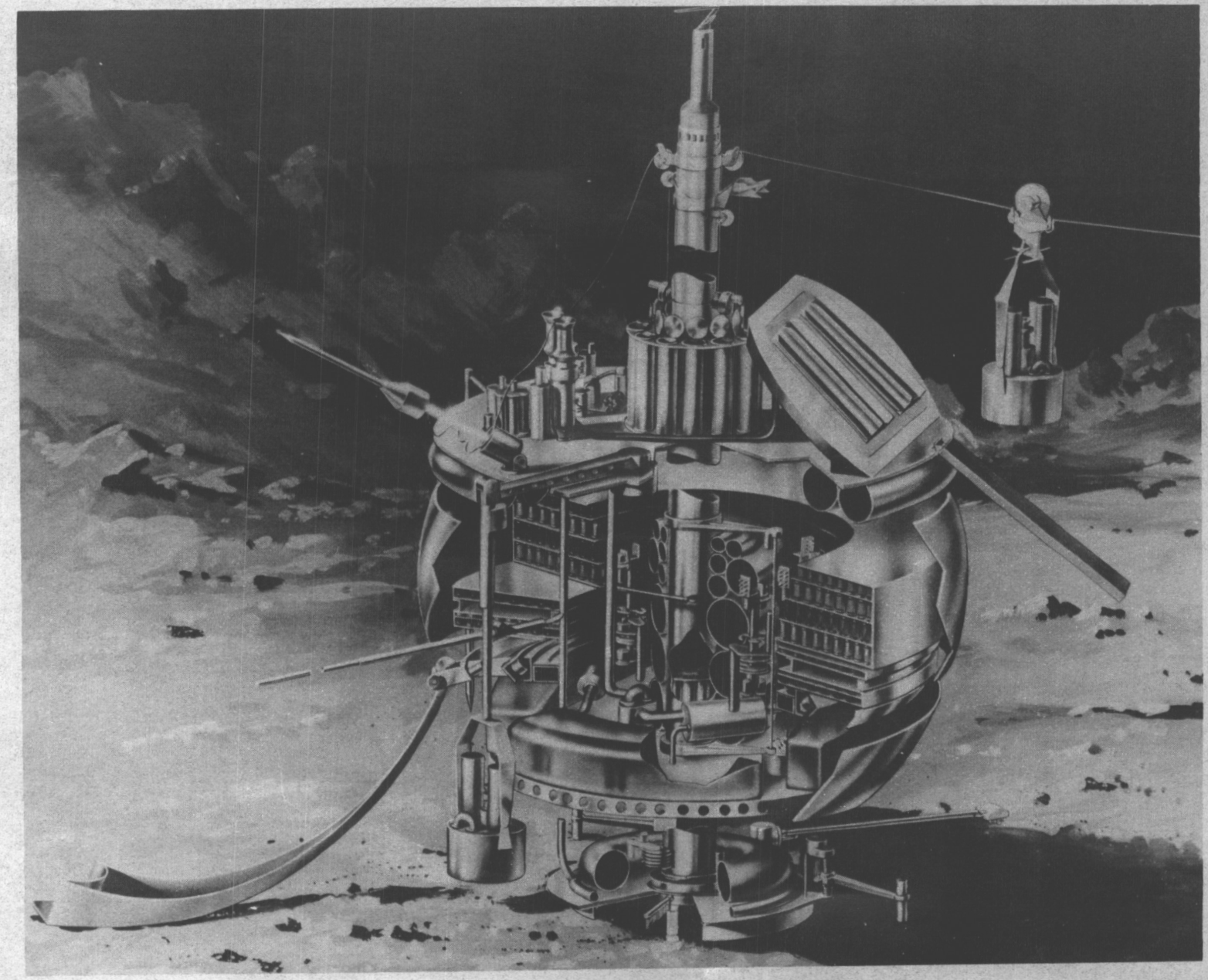

ABL DESIGN POINT CONFIGURATION

ABSTRACT

This report, in six volumes, contains the results of a twelve-month study conducted for the Bioscience Programs Division, Office of Space Science and Applications, of NASA Headquarters by the Aeronutronic Division of the Philco Corporation. The feasibility of an automated biological laboratory (ABL) for use in the exploration of Mars was investigated. The objectives of the study included definition of the scientific objectives for such a mission, selection of a representative complement of experiments, definition of the required instrument complement, performance of a preliminary design feasibility study for a representative design point payload, and the execution of a program definition and development plan. The first objectives were attained in the study through interviews, discussions, and reviews with scientists in government, academic institutions, and industrial concerns. Desirable objectives and approaches to the biological exploration of Mars were defined. A great many possible experiments, both biological and physical, were evaluated and ranked numerically. A complement of 35 such experiments were selected for purposes of establishing a representative instrumentation payload for a Voyager-class landing mission to Mars in 1975. This payload was used as a basis for conducting a preliminary design feasibility evaluation of an automated biological laboratory.

The concept for an ABL investigated in this study was a departure from current concepts in scientific payload organization. In the ABL concept the experimental program is conducted, not with individually mechanized experiments, but by an integrated complement of basic instruments operated in a sequential fashion, in the same way biological experimentation is performed in terrestrial laboratories. The laboratory is controlled by an on-board computer, with command override capability provided for Earth-based scientists to select alternative experimental programs, or even to initiate completely new programs, in response to the results obtained from preceding experiments. The study results indicate several advantages accruing to the ABL concept. The most important of these is that far more

meaningful scientific results are possible from a given instrument complement operated in this manner than for the same instrument complement operated as fixed predesigned experiments. In addition, weight and reliability advantages are also demonstrated for the concept.

The design point landed payload was designed for two year (Earth) life on the surface of Mars and resulted in an approximately spherical configuration, 68 inches in diameter weighing approximately 1200 pounds.

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ACKNOWLEDGMENTS

The ABL study effort brought together in a unique manner the combined demands of the sciences of biology and space physics, and the disciplines inherent in space payload systems engineering. As would be expected, the interfaces were many and varied and frequently posed complex problems. The contributions of numerous individuals and groups in government and the scientific community to the solution of these problems helped significantly to increase the depth and validity of this study. All such sources are gratefully acknowledged. In particular, the following sources proved helpful:

- The contributions made by the nearly 150 individual scientists interviewed in the processes of defining the scientific objectives of this program were particularly beneficial. These individuals are identified in Appendix I of Volume VI.

- Attendance by Aeronutronic personnel at meetings of the Exobiology Summer Study of the National Academy of Sciences held at Stanford University during the summer months of 1964, and at the Rockefeller Institute Sessions that autumn, personal discussions with various individual members of this study group, and provision of various working papers of the groups to the Aeronutronic study team, all proved exceedingly helpful in the conduct of this study.

- Attendance by Aeronutronic personnel at meetings of the Biosciences Subcommittee of the Space Science Steering Committee of NASA over the period of this program, free discussions with various members of the committee in working sessions, and permission to present interim results of the ABL study to the committee for their constructive criticism, contributed significantly to the useful prosecution of the study.

- The results of the ad hoc Bioscience Working Group which met in Newport Beach, 22-26 March 1965, and particularly the recommendations of the Committee on Martian Landers chaired by Dr. Wolf Vishniac, were most useful in helping to establish ABL goals and objectives on a sound scientific footing.

Special attention was paid during this study to keeping abreast of the very significant work in exobiology and related science underway in the various NASA and other government laboratories. Of particular significance to the ABL study were frequent discussions with Dr. George Hobby and members of his biosciences organization at JPL, the work in biologically-related instrumentation under development by Dr. Gerald Soffin's bioinstrumentation group at JPL, and valued discussions on many aspects of exobiological exploration with Dr. Richard Young and members of his Exobiology Department at NASA Ames Research Center.

Many other persons, in government, academic institutions, and industrial laboratories have given generously of their time and ideas and their efforts are gratefully acknowledged. Thanks are also most specifically due to the members of the Bioscience Programs Division of NASA Headquarters under Dr. Orr Reynolds for their valued guidance and assistance in providing information and counsel in the direction of this study.

This study was performed by the Aeronutronic Division of the Philco Corporation under the direction of the Space and Re-entry Systems Operation. Mr. William Hostetler was Program Manager. Technical responsibility for execution of the study was under the Office of Chief Engineer for Space and Re-entry Systems. Mr. Temple W. Neumann was Program Engineer. The principal members of the study team were drawn from the Aeronutronic Engineering Directorate and the Applied Research Laboratory. The principal contributors and their fields of speciality are given below:

Dr. Robert E. Kay	Manager, Biosciences Department, Applied Research Laboratory
Dr. Ross Bean	Biochemistry
Dr. C. D'Agostino	Physical Chemistry
Dr. Hugh Ells	Biology
Dr. Richard Walwick	Biochemistry
Dr. Donald Garwood	Supervisor, Environmental Analysis Section, Space Physics Department, Applied Research Laboratory
Mr. Harry Taussig	Space Physics and Instrumentation

Mr. Wilfred Bachle	Supervisor, Advanced Design, Space Physics Department, Applied Research Laboratory
Mr. Marchal Caldwell	Preliminary Design
Mr. Ralph Irwin	Vehicle Synthesis
Mr. Richard K. Simmons	Systems Analysis
Dr. John B. Opfell	Sterilization
Mr. Warren Link	Supervisor, Data Handling Section, Engineering
Mr. Fritz P. Conroy	Telecommunications
Mr. Richard Lowie	Computer Systems Analysis
Mr. William Pile	Computer Design
Mr. George P. Zebal	Senior Staff, Geologist, Applied Research Laboratory
Mr. Duane Johnson	Astrodynamics
Mr. Donald Derengowski	Reliability Analysis

In addition to the above principal study team members, significant contributions were made to this study by the following Aeronutronic specialists:

Mr. Gale Bilyeu	Mr. Ronald Mitchell
Mr. Eldon Cade	Mr. Clarence Munsey
Mr. Hakchill Chan	Mr. Richard Peterson
Dr. David Garber	Dr. Henry Shanfield
Mr. Harry Graham	Mr. James Van Meter
Dr. James Hanrahan	Mr. Rodney Mills
Mr. Joseph Hawkins	Mr. Web Westerman
Mr. Lyle Lerum	Miss Beruta Zalite

SECTION 1

INTRODUCTION

It was with a great deal of forethought that NASA undertook, in 1964, the systematic investigation of the concepts underlying an automated biological laboratory (ABL) for use in the scientific exploration of the planets. Let us state at the outset that these concepts embody a completely new approach to the scientific exploration of space. They are, in short, a recognition of the fact that at some stage of Martian explorations we must be capable of carrying out scientific investigations, rather than a number of preprogrammed experiments. Basic to the recognition of a requirement for an ABL were the fundamental differences between the manner in which scientific biological research is conducted in terrestrial laboratories (through ordered sequential investigations building on preceding results), and current methods of space investigations employing multiple independent experiments. Whatever else a space payload may be with regard to size, weight, complexity, or number of experiments, it falls short of achieving the objectives of an ABL if it fails to provide for this correlated, sequential experimentation basic to sound biological research.

Implementing such a concept of planetary exploration is a formidable task. Laboratory procedures and techniques that are performed routinely by scientists and technicians must be performed remotely, automatically, and reliably for long periods of time without direct human intervention. The subtle and sophisticated reasoning, planning, and execution that lies behind well-conducted research in terrestrial laboratories must be incorporated into the careful original design and mechanization of ABL experiments, instruments, and a flexibly-formatted control system. The task is, however, by no means impossible. The analyses covered by this study have evaluated the many separate aspects of such a mission. Many areas have been revealed in which improvements in today's state of the art

are required. However, these advances, without exception, are orderly and reasonable extrapolations of today's art and well within our capability for achieving mid-1970 launch dates. No quantum steps in technology improvement are required or have been postulated for the concepts presented in this report.

While admittedly a significant scientific and technical undertaking, the rewards accruing to the development of a planetary exploration research payload based on the ABL concept make it eminently worthwhile. The only possible exploration technique offering comparable scientific return is manned exploration, a far more costly approach. While an important long-range objective of our space program, manned exploration entails long delays to achieve these same objectives. An ABL soundly based on proven scientific methods is a logical and efficient interim step between current exploration techniques and the complex manned missions to come. As will be described elsewhere in this volume, other concepts for organizing unmanned exploration payloads cannot possibly achieve equivalent scientific results.

Because the concept of an ABL is so fundamentally related to the methods of science, it was essential that scientific objectives and methodology be considered in its development from the beginning. At the direction of NASA's Bioscience Programs Division, Aeronutronic was instructed to investigate the desirable scientific objectives and the experimental and instrumental composition of such a payload. In this task we were directed to, and did, elicit comments, recommendations, and technical support from individual scientists, established scientific bodies such as the National Academy of Science (and in particular, the Bioscience Subcommittee), various ad hoc and informal working and consultive groups in exobiology, and various individuals and organizations within NASA centers working in exobiology or related fields. The considerable scientific contribution from these many sources is reflected in the results of this study and is gratefully acknowledged.

At the same time, the considerable diversity of views represented could not be reflected in an engineering feasibility study which must consider limitations of technological state of the art, launch opportunities, program funding, and many, many other constraints. Accordingly, it fell to the Bioscience and Space Physics staff of Aeronutronic's Research Laboratory to analyze and interpret these contributions to provide an orderly set of objectives and experiments from which a meaningful engineering preliminary design and feasibility analysis could be accomplished. While it is felt that the resulting objectives and experiment complement fairly represent the best consensus of the many suggestions and recommendations received, it is recognized that others might also have been selected. It will be shown elsewhere in this report, however, that this factor was not critical to achieve the ultimate objectives of the engineering feasibility evaluation. This was true because the selected objectives and experiments

defined a laboratory capability which was sufficiently comprehensive to accommodate the probable experimental programs that may be suggested for the early- to mid-1970 time period. That is, most engineering problems expected in payloads of this kind have been revealed by the laboratory design selected. These problems have been analyzed in considerable detail in this study, and solutions have either been found, or the remaining critical factors identified and straightforward development requirements set forth.

The results of the present study have demonstrated the significant scientific advantages which were expected to accrue to the ABL concept through more meaningful biological research. Very significant system engineering advantages also accrue to this concept, as is clearly demonstrated in the analyses of Volume III, and this is one of the more significant results of this study. The further demonstrated feasibility for attaining this capability in time for mid-1970's launch opportunities makes the ABL concept one worthy of further serious attention by both NASA and the scientific community.

The analyses relating to the selection of scientific objectives and the resulting scientific payload for the ABL are described in the remainder of this Volume (II). Systems engineering analyses of the resulting payload and mission functions will be found in Volume III.

SECTION 2

DEFINITION OF SCIENTIFIC OBJECTIVES

2.1 INTRODUCTION

The design of an ABL for performing biological exploration of the planets requires first the definition of what such a laboratory will be required to accomplish. It was for this reason that an evaluation of desirable scientific objectives became an essential element of the engineering feasibility and preliminary design study covered by this study. It was, likewise, imperative that the scientific objectives be established as early in the study as possible so that the primary task of engineering evaluation and design could be undertaken. To accomplish this, data applicable to the determination of the scientific objectives was gathered concurrently from a number of sources. The results of this effort are of great importance to the program since they define the complexity of the experimental complement required on an ABL, and indicate the long-term, complex nature of the exobiological exploration problem. A significant additional factor was that the direct contact of Aeronutronic scientists with individual scientists and groups of scientists served to stimulate the interest of the scientific community in the NASA exobiology program. In many instances these interviews provided scientists with their first contact with this program.

The information gained made it readily apparent that the scientific community has extremely broad objectives for the biological exploration of Mars. These objectives strongly indicate the necessity for a definite type of ABL. It appears that for the accomplishement of many of the objectives, an ABL with a broad spectrum of general biological, geological, chemical and physical laboratory equipment is required. Furthermore, this equipment must be automated to perform specific experiments as directed by

internal control and by instructions from earth, and it must be possible to use experimental results as feedback to determine the next logical experimental step in the scientific investigation. That is to say, at some stage of the Martian exploration the ABL must be capable of carrying out a scientific investigation rather than a number of preprogrammed experiments.

2.2 METHODS

2.2.1 SOURCES OF INFORMATION

The following possible methods of obtaining information needed to determine scientific objectives of an ABL were considered:

(1) An analysis of published information by experts in the field of extraterrestrial biology and related areas.

(2) Personal consultation by Aeronutronic scientists with the scientific community including committees and scientific study groups.

(3) Attendance and participation of Aeronutronic scientists at scientific meetings.

(4) Internal consultation among Aeronutronic scientists.

(5) The use of a questionnaire of either the subjective or objective type which would be sent to prominent scientists.

Each of these methods, except the last, was used. Questionnaires were not employed because they are in many respects repetitious of, but less satisfactory than, personal consultations. In addition, the objective questionnaire has the disadvantage of having built into the questions a specific direction of thought which does not allow the latitude of response obtained in a personal interview. The subjective questionnaire generally requires an essay type of response and past experience has indicated that few people reply to such questionnaires.

Considerable useful information was obtained by attendance at the NAS Space Science Board's Summer Study on Exobiology held at Stanford University during the summer of 1964, and at a number of meetings of the Bioscience Subcommittee of the National Academy of Science. At several of the Bioscience Subcommittee Meetings status reports were given to the members by Aeronutronic personnel. These opportunities to present our findings were helpful and permitted the members of the subcommittee to offer suggestions in regard to our methods and interpretations while the task was being conducted. The methods of investigation were revised and improved thereby as the task progressed.

2.2.2 METHODS OF INFORMATION ANALYSIS

The data gathered from the literature was analyzed to derive the goals which seemed to be implied from: (1) assumptions concerning Martian biology, (2) stated objectives of contemplated probes, (3) specific techniques and equipment suggested for use in the scientific exploration of Mars, (4) suggested preparatory experiments to be conducted in terrestrial laboratories and (5) the expressed desirability of the biological exploration of space.

The literature reviewed prior to September 1964 was selected from references (1) through (5). During the period between September 1964 and April 1965 a continuous current literature search was conducted. Pertinent articles were compiled and annotated to form a bibliography containing 425 references dealing with various aspects of the problem of detecting extraterrestrial life with special emphasis on techniques and instruments. This bibliography forms Volume IV of this report.

The initial effort by Aeronutronic scientists to contact members of the scientific community consisted of a letter to prominent scientists asking for an oral interview to discuss their ideas and opinions concerning the scientific objectives of an ABL. A follow-on letter explaining the program in more detail was sent to a number of scientists who wished additional information prior to the interview. Subsequently, 144 scientists were interviewed by senior members of Aeronutronic's Biosciences staff. The data is briefly summarized in Table 2.I. The information obtained by these consultations was analyzed in the same manner as that gathered from the literature. However, since this part of the investigation was especially sensitive to the sample of the scientific community contacted, additional detailed information about the nature of the interviews was prepared. This included: (1) tabulation of the responses to our letter requesting an interview, (2) a breakdown of the type of interviews conducted (i.e., individual, small groups or large groups), (3) the composition, by discipline and institutional affiliation, of scientists interviewed, and (4) the percentage of the scientists interviewed who were engaged in professional activities directly related to exobiology. This information, together with an analysis of the interviews will be found in Appendix 2 of Volume VI of this report.

TABLE 2.I

SUMMARY DATA FROM INTERVIEWS WITH SCIENTISTS

1.	No. Scientists Contacted by Letter:	355
2.	No. Scientists Interviewed:	144
3.	Disciplinary Distribution	
	Biologists:	110 (incl. 40 Biochemists)
	Chemists:	17
	Physicists:	8
	Engineers:	9
4.	Professional Affiliation	
	Academic Institutions:	75%
	Industrial Concerns:	25%
5.	Professional Activities	
	Related to Exobiology:	25%
	Not Related to Exobiology:	75%

(Note: Percentage distribution in 4 and 5 above does not correlate on an individual basis.)

2.3 RESULTS

The direct responses of scientists to interview questions and the search of the literature constituted the most tangible part of the effort to define the basis for the scientific objectives of the ABL. With few exceptions, life detection and its partial characterization were specifically stated to be the primary scientific objectives. However, other (sometimes long-range) objectives emerged from the analyses. In general, the expressed objectives are included in one of the topics indicated in Table 2.II.

TABLE 2.II

EXPRESSED GOALS FOR THE BIOLOGICAL EXPLORATION OF MARS

1. Detect life.
2. Chemically and physiologically characterize the life forms detected.
3. Determine if such life has a common origin with life on Earth (this includes both the intertransfer of life between Mars and Earth and common chemical evolution).
4. Establish the evolutionary pathway of Martian life.
5. Determine the interaction of life forms with the environment.
6. If life is not found, discover the factors which prevented its development, and determine the state of chemical evolution on Mars.
7. Look for fossil life and, if only fossils are found, determine the factors associated with the extinction of life.

Obviously, the information obtained was not always explicitly stated in the form given in the table and its fit within one of these categories is somewhat subject to the interpretation of the interviewer. For example, the investigation of the evolutionary pathways of Martian life was considered to include suggestions which were made to investigate genetics and information transfer.

It was of interest that the majority of scientists expressed enthusiasm for a program directed toward the search for extraterrestrial life, but a number felt the scientific and technological fallout would outweigh any intrinsic scientific merits. There were a few dissenting scientists who were completely opposed to the program. A conscientious effort was made to include in the list members of the scientific community whose pronouncements had been unfavorable to a program for detection of life on Mars. Curiously, the majority of these individuals did not even acknowledge receipt of the request for an interview. This result suggests that the sample interviewed may have been biased in favor of the search for life on Mars, or at least was not biased against such a search.

Both the literature survey and the interviews indicated that scientists expected Martian life to be constructed and to function in a manner analoguous to terrestrial forms and to be based on the same chemical entitites and physical principles as terrestrial life. In regard to the composition

of living things, the opinion of the majority of the scientific community contacted has been well expressed by Urey[6] as follows: "There is no known chemistry of other elements which approaches in ordered complexity that of carbon, nitrogen, oxygen and hydrogen, and we know enough of the chemistry of all the elements that we can be certain that no other such chemistry exists. Only these elements supply such a complexity of compounds and chemical reactions that we are forced to conclude that only the chemistry of these elements could supply the complexity of structure and behavior which we recognize as those of living things. A system of life based on other elements would necessarily be so vastly simpler in behavior that we would not recognize it as such."

2.4 DISCUSSION

2.4.1 GENERAL

The scientific objectives for the biological exploration of Mars as expressed by those scientists interviewed or contacted in the course of the study, are extremely broad. In fact, the expressed goals involve essentially the same type of studies being pursued in terrestrial biology today. Since most of these objectives have not been attained for terrestrial life, it is obvious that all of them cannot be accomplished by a single biological probe on Mars. These findings, therefore, strongly imply the need for a progression of investigations, each increasing in complexity. The first investigation for use in the 1970's should be designed to achieve the basic objective of detecting life, since the detection of life is an essential forerunner to most of the other stated goals. Subsequent investigations should attempt progressively more detailed characterization of life forms detected.

2.4.2 REQUIREMENTS OF EXPERIMENTAL DESIGN

In all experimental programs the objectives dictate experimental design. Therefore, it is appropriate to consider the special experimental design problems which are inherent in the objective to detect life. Detection of alien life is probably one of the most difficult tasks which can be proposed, since no simple satisfactory definition of life has been made. Definitions which have been proposed make it necessary to consider a number of complex phenomena and materials. One of the ways to define life is to enumerate the properties of systems which are considered to be living. When this is done, it is apparent that life has <u>many</u> properties, no one of which is sufficient to define it. Consequently, the confidence with which one can conclude that an entity is a living system increases with the number of these attributes which can be demonstrated. However, the number of attributes demonstrated is not the only important criterion. The specific nature of the attribute is of vital interest, since many scientists consider certain attributes of life to be more distinctive of living systems than others. The information obtained by the search of the

literature and consultation with scientists indicates that the properties presented in Table 2.III are those most often mentioned in connection with living systems. Therefore, to detect life it seems most reasonable to conduct experiments which demonstrate these properties. This implies that a number of experiments designed to demonstrate different properties are needed and that experiments which demonstrate more than one property may be especially valuable.

TABLE 2.III

MOST FREQUENTLY CONSIDERED
ESSENTIAL PROPERTIES OF LIFE

1. Transfer and conversion of energy.
2. Association with molecular aggregate of macromolecules.
3. Ability to replicate, reproduce and grow (including information storage, transfer and processing).
4. Association with proteins, nucleic acids, lipids, carbohydrates, and certain other unique substances.
5. Possession of catalytic activity.
6. Organization, both macrostructural and molecular (including optical activity).
7. Ability to mutate.
8. Ability to respond to stimuli (irritability).
9. Functions in an aqueous environment.

In addition to life detection experiments, it is also essential to include environmental experiments which will provide information for use in the performance and interpretation of the biological investigation. The inclusion of the environmental experiments also provides capability which permits useful characterizations of other kinds to be performed, such as geological, meteorological, and paleontological. Such capability makes it possible to obtain useful information even if the selected life detection experiments produce negative results. For these reasons a comprehensive complement of both life detection and environmental experiments should form the basis of any investigation to detect life on Mars.

2.4.3 PHILOSOPHY OF EXPERIMENT DESIGN FOR ABL

While the selection of scientifically sound and meaningful experiments to satisfy the above requirements was both important and necessary to the conduct of this study (as discussed in detail in the following section of

this volume), of greater concern was the formulation of methods for conducting these experiments that would maximize the scientific return from a given instrumental capability. The analyses performed indicated that there are preferential methods of experiment design which should form the basis of an ABL. Furthermore, the application of these preferred methods to even a portion of the experiment package can significantly improve the quality of the scientific investigation performed on Mars. These methods are discussed below.

a. The Nature of the Sample. The nature of the sample used in scientific investigations is an exceedingly important consideration in the design of experiments. This is even more true of the ABL than in terrestrial investigations because detailed interpretation of results by the human investigator is hampered by remote operation and limited bandwidth communication capability. A number of characteristics of the sample are of interest, from the point of view of the philosophy of experiment design.*

(1) Correlation of Experimental Results. Many experiments must be performed if the multiple corroborative indications of life identified in the preceding paragraph are to be obtained. Furthermore, these results must be correlative if they are, in fact, to serve as cumulative evidence for the presence of life. For example, consider two experiments, one to detect catalytic activity and the other protein. Each is conducted using both common and separate samples, as indicated in Figure 2-1. In each case, catalytic activity is found, but protein is not. In the case where the experiments use separate samples they are essentially not correlative. The information resulting from the experiment is only that in one area there is a catalytic agent and in a second area there is no protein. Nothing can be said about the nature of the catalyst and the information that protein is absent is not useful. On the other hand, the data from the experiments using a common sample is correlative, and (provided the sensitivities of the two tests are the same) it can be concluded that the catalytic agent is not an enzyme, because protein is absent and all enzymes are proteins. In this case, the negative finding has meaning because it supplies information about the catalyst.

*Here we are not concerned about the physical description or mechanical collection of the sample, which is discussed in detail in Volume III in connection with sample collection, but rather with gross statistical properties of the sample and their effect on interpretation of results.

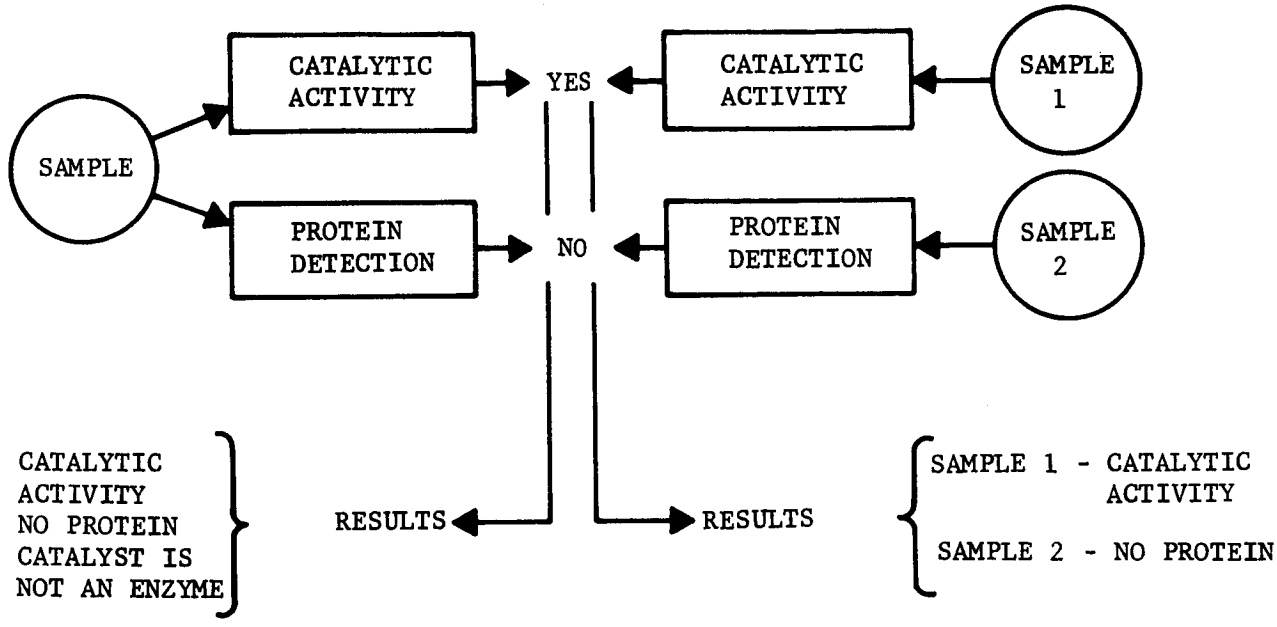

FIGURE 2-1. EFFECT OF SAMPLE ON RESULTS FROM IDENTICAL EXPERIMENTS

(2) Sensitivity. Consider the same two experiments described above (and in Figure 2-1) from another point of view, that of sensitivity. Many of the life detection experiments evaluated (see Section 3) will be working near their limit of sensitivity if sample sizes are moderate (compatible with reasonable sample collection and processing capabilities) and if the distribution of organisms in Martian soil is comparable to desert soils on Earth. The importance of keeping the concentration of biological material as high as possible for each experiment is apparent. In the example case, it would be an appropriate comparison to assume that the total sample collection and processing capability would be the same for the two payloads. (Sample collection and processing in an ABL-class payload constitutes a significant part of the total system weight and power allotment and cannot be extended indefinitely). If this were true, the experiments utilizing a common sample would benefit from twice as rich a sample as would the experiments which had to share the same total quantity of biological material.

The above statement is true, of course, only if the sample is homogeneous. If terrestrial analogy is any indication, this is far from the case, however. While life forms may be (relatively) ubiquitous, they are not absolutely uniformly distributed in samples of the size of one kilogram or

less. Thus, if a sample contains organic material distributed approximately as shown in Figure 2-2, the probability is high that one of the two separate experiments would receive a higher than average amount and the other, less. If the average sample richness represented marginal concentration of biological material for the experiment sensitivities in question, the experiment receiving Sample 1 could easily produce a false-negative result. Greater division of the sample to supply more individual experiments can be seen to multiply this undesirable effect. Hence, what began as a concern about sample richness and experiment sensitivity can be seen to have relevence for the problem of the correlativity of experimental results as well. This example serves to confirm the lack of confidence in the correlativity of experimental results from separate experiments which was assumed in the discussion in Paragraph (1) above.

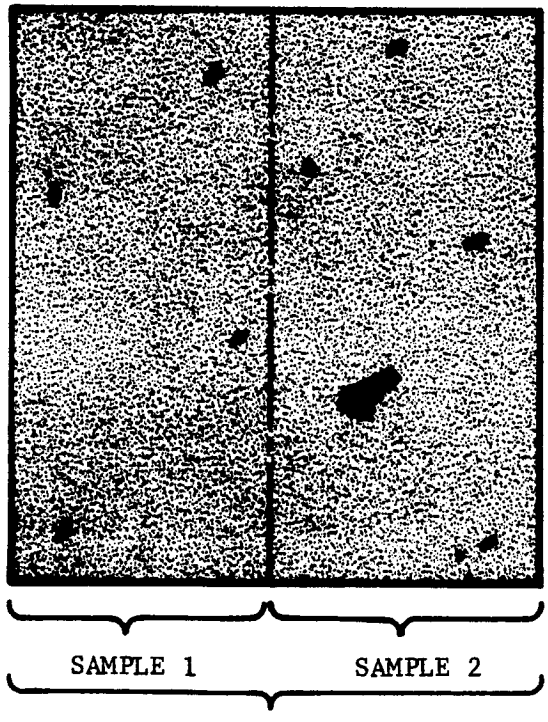

FIGURE 2-2. EFFECT OF SAMPLE DIVISION ON BIOLOGICAL CONTENT

b. Program Flexibility and Feed-Back of Results. A second class of methods, relating to experiment design, concerns the manner in which the available equipment is organized and controlled. In the previous example, illustrated in Figure 2-1, both sets of experiments utilized independent experimental apparatus which, once turned on, ran to completion and then terminated the experiment. This procedure is typical of current space payload experiment design philosophy. Such preselected experiments can be

rerun, even with different samples, but they cannot be modified. It is interesting to note, however, that this approach deviates appreciably from the experimental procedure employed in most biological research in terrestrial laboratories. In such research, overall objectives are established and general experimental procedures are defined to attain these objectives, but at each stage of the research the details of the subsequent experimental steps are re-evaluated in light of the preceding results and if necessary modified to produce the most meaningful results from the next experiment. Thus, when a scientist is concerned with experimentally establishing the validity of a proposition, he uses an experimental plan which allows reflective type of thinking in which one step leads in an orderly way to the next until a satisfactory conclusion can be drawn. If he desires to obtain the most meaningful conclusion he does not arbitrarily terminate the experiments after performing a fixed number of preselected experiments. It is this very experimental process that takes advantage of unforseen results, a traditionally rich source of new data. It also maximizes the conclusions that can be drawn, and therefore the information content, of a given amount of experimental data.

To contrast these two alternatives consider the conduct of a purely hypothetical investigation designed to test the validity of the statement, "Porifera do not produce phosphocreatine." The investigation can be conducted by carrying out three logical, preconceived experiments. It can also be performed by conducting an initial experiment and selecting subsequent experiments on the basis of the results which accrue as experiments are performed. A reasonable set of fixed experiments could be the following:

(1) Examine different members of the phyla Porifera for the occurrence of phosphocreatine.

(2) Examine species which contain phosphocreatine for the occurrence of guanidoacetate, the immediate precursor of creatine.

(3) Examine species which contain guanidoacetate and phosphocreatine. For their ability to methylate guanidoacetate and thereby produce creatine.

Suppose the results of these experiments are as follows:

(1) Thetia lyncurium is found to contain phosphocreatine in substantial amounts.

(2) Both guanidoacetate and its methylating enzyme are present in T. lyncurium.

The conclusions which can be drawn from these results are:

(1) At least one species of Porifera contains phosphocreatine.

(2) The species of Porifera which contains phosphocreatine also contains the immediate precursor of creatine and the enzyme which converts it to creatine. This evidence is inadequate to test the validity of statement, "Porifera do not produce phosphocreatine." However, the bulk of the evidence does seem to indicate that phosphocreatine is produced by T. lyncurium.

However, if we are free to continue conducting experiments, sufficient evidence to answer the questions may be obtained.

Let the next experiment be to assay T. lyncurium for creatine phosphokinase, an enzyme which converts creatine to phosphocreatine, and suppose it cannot be detected. It then becomes necessary to either (1) postulate a new mechanism for the formation of phosphocreatine in T. lyncurium or (2) conclude it is not produced, or (3) attribute the results to an inadequate assay procedure. Since phosphocreatine is present in T. lyncurium one is tempted to favor case (1) or (3). However, there is another possibility directly related to case (2) which can be tested by direct experimentation. This possibility is that the phosphocreatine present in T. lyncurium is derived from an exogenous source. To test this hypothesis T. lyncurium is grown in a medium rigorously free of phosphocreatine and of other organisms known to produce phosphocreatine. All of the experiments are then repeated using T. lyncurium free of exogeneous sources of phosphocreatine. The results are as follows:

(1) No phosphocreatine is detected.

(2) Both guanidoacetate and its methylating enzyme are present.

(3) No creatine phosphokinase is detected.

The evidence now strongly supports a conclusion which is exactly the opposite of that suggested by the fixed set of experiments. That is, phosphocreatine is not produced by T. lyncurium. In addition, a great deal more information about T. lyncurium has been obtained. It is indicated that (1) this organism has a unique ability to extract phosphocreatine from the environment and concentrate it in its tissue, (2) the inability of T. lyncurium to synthesize phosphocreatine may be due to a lack of creatine phosphokinase and (3) since phosphocreatine is apparently stored it does not readily enter into the metabolism of T. lyncurium.

It might be argued that through experience with other biological systems the fixed experiments should have been to look for phosphocreatine and, when it was found, to determine whether it is derived from an exogenous source. But experience tells us almost nothing about Martian organisms and the Martian environment. Thus, in the case of exobiology, it becomes extremely difficult to pick critical fixed experiments. Those selected could easily be of much less relevance than those in the example considered here. Therefore, it seems prudent, in the case of exobiology experiments, to allow flexibility in the experimental format and the opportunity to conduct a large series of experiments, each one based on the results which accrue from the preceding experiments. In regard to the ABL, it is also important to point out that, as in the example considered, a more extensive instrument complement is not necessarily required to conduct experiments in this manner. In fact, in some cases less equipment may be required.

To illustrate these last points consider the payload organizations depicted in Figure 2-3. On the right are represented five individually mechanized experiments. (Sample utilization is not considered in this example. However, the previous discussion would argue for common sample usage in all cases, which may be assumed for this discussion). These experiments, in the manner of current practice, are preselected and are not modified after launch. The actual experiments selected for this example were taken from the list of those that have been suggested for ABL (see Section 3). Let it be assumed that each experiment is performed successfully, the indicated results are obtained and that the results correctly reflect the true conditions within the sample.

Let us now consider an alternative deployment of the available resources, i.e., the processing equipment and instrumentation capability of these experiments. The equipment complement contained in the individual experiments is listed on the right. Since the first experiment performed with any experiment arrangement must be preplanned, because no information is available to modify it, the previously selected initial experiment is as good a selection as any. It is shown on the left in Figure 2-3 as the initial experiment and, having used the same equipment and same sample assumed in the previous case, the results are, of course, the same.

Now, however, let it be assumed that the next experiment is not predetermined and, further, that any experiment may be selected which can be performed with the available instrument complement operated in any desired sequence. Of this almost infinite number of possible experiments assume the experimentor selects the one indicated in the second level on the left in Figure 2-3, and that the results are as indicated. In response to this result, the experimentor is again free to select an experiment of his choice and so on until he has exhausted the usefulness of the available analytical procedures (limited only by the supply of consumables, electrical power and/or time). He is not limited to the number of experiments represented by the same instrument capability mechanized as

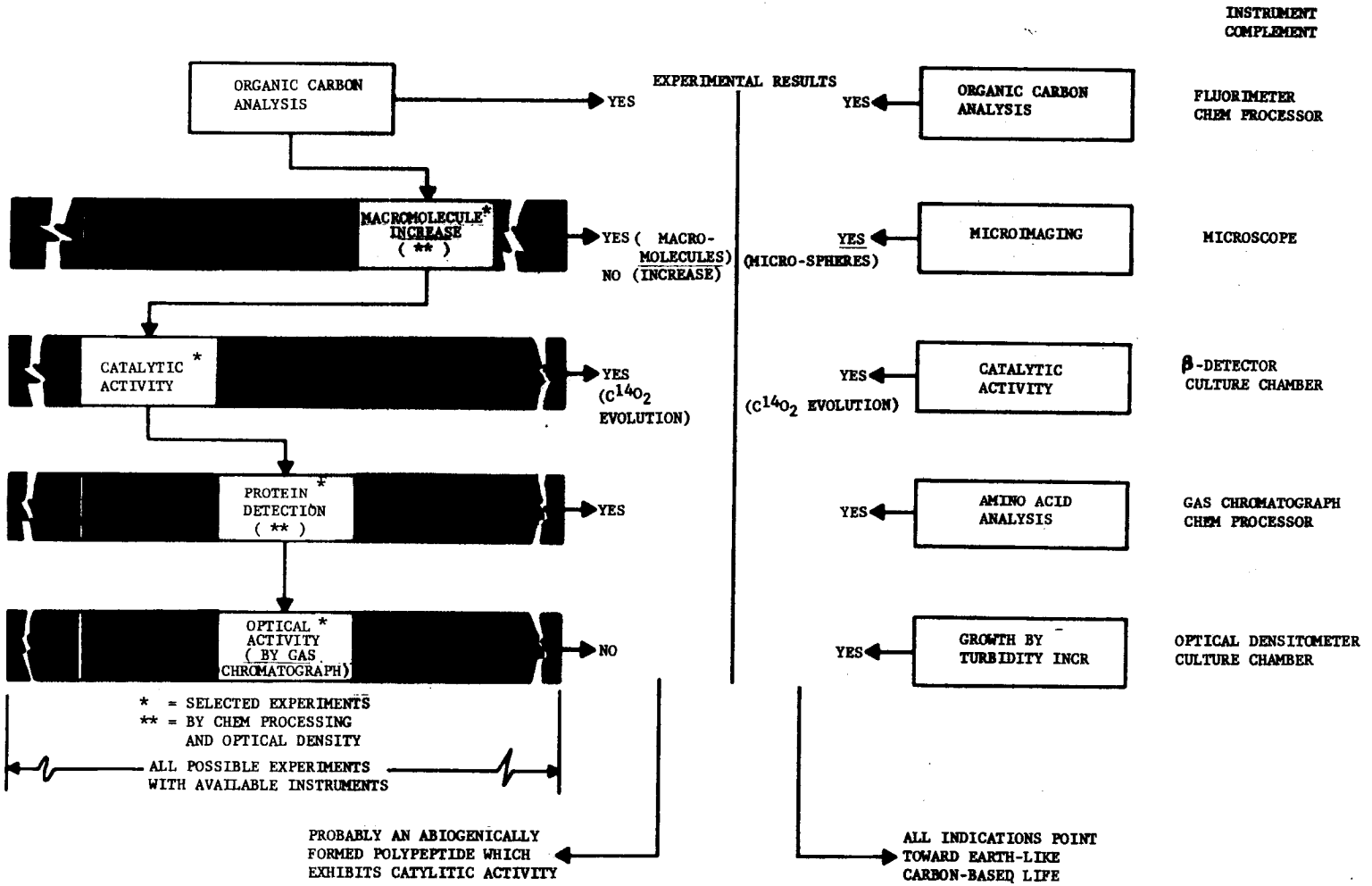

FIGURE 2-3. COMPARISON OF EFFECT OF EQUIPMENT ORGANIZATION

individual experiments, but can continue the investigation as long as meaningful scientific results are obtained. For purposes of this example, however, let us terminate the analogy with equal number of experiments for both cases, as indicated in Figure 2-3, and examine the results. It is clear that even from the limited number of freely selected experiments more biologically significant conclusions can be reached regarding the sample than from the preselected group, and far more total information about the sample is obtained.

Again, it might be argued that the selected individual experiments in this example were unnecessarily restrictive. This is not the case. The significant point is that the individual experiments are preselected and have a relatively small finite number. Once any such complement of experiments is selected it is a relatively simple matter to construct an alternative hypothetical, but nontheless realistic, experimental sequence which will yield more information under the postulated conditions.

The further advantage of this approach, namely common use of equipment, also can be seen in the example of Figure 2-3. Note that two of the individual experiments employ culture chambers and two employ chemical processing equipment. One of each of these pieces of equipment only need be carried to perform the experiments on the left in Figure 2-3. While some redundancy will undoubtedly be desirable for reliability reasons, when the number of individual experiments becomes large, as it will in Voyager-class payloads, the duplicity of equipment becomes a major concern, and far more than is necessary to simply satisfy the reliability redundancy considerations. These factors are discussed at length in Volume III under the engineering considerations of payload design.

2.5 CONCLUSIONS

The foregoing considerations together with similar information obtained from discussions with scientists and the various consultive groups have indicated that the following factors are of particular importance in planning the scientific objectives and approaches for the ABL: (1) life cannot be detected with certainty; we only become more confident in our judgment as the amount of correlative information increases, (2) the distribution of life within almost any possible sampling area is not uniform and the distribution patterns are unpredictable, (3) living things are extremely variable in the nature and number of properties they exhibit, and (4) life is a dynamic process which exhibits different properties at different times, often in an unpredictable manner.

These factors form the basis for the reason successful life-detection experiments cannot be performed in the same manner as physical experiments which have been conducted as part of the space program. In most physical experiments which have been conducted, the entity or phenomena studied exists uniformly or in a predictable pattern (which could be established

if need be by the experiment) within the volume to be sampled. The entity, in general, behaves according to well-understood physical principles. In addition, for each specific entity or phenomena, the number and nature of the properties which describe it remain the same. Thus, there is a high degree of certainty and predictability in such physical experiments. Therefore, it is possible to correlate, with confidence, the information obtained from separate experiments and to estimate the condition within the volume bounded by the data points. Life detection experiments, on the other hand, are uncertain and unpredictable simply because of the nature of life. In fact, Good[7] in a sense defined uncertainty as life when he said, "Some billion years ago, an anonymous speck of protoplasm protruded the first primative pseudopodium into the primeval slime, and perhaps the first state of uncertainty occurred."

Thus, because of this uncertainty, the preferred methods for accomplishing life-detection experiments embody an integrated approach which maximizes the confidence in the correlativity of the data and uses feedback to determine logical procedures for providing the greatest evidence upon which to base conclusions. These methods are those upon which the design of an integrated, automated biological laboratory (ABL) is based. An experimental payload becomes an ABL because these preferred methods are incorporated in the design. It does not become an ABL because of its size, mechanical complexity, the presence of a particular piece of equipment, or the number of experiments it contains.

2.6 REFERENCES

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SECTION 3

DEFINITION OF BIOLOGICAL EXPERIMENTS

3.1 INTRODUCTION

To evaluate the engineering feasibility of accomplishing the scientific objectives set forth in Section 2, it was necessary to postulate an equipment complement for the ABL. While a broad spectrum of processing and analytical instruments is called for by the scientific objectives outlined, it seemed most reasonable to identify such an equipment complement in relation to specific experimental capability, even though such a complement would not be limited to a specific experiment list once it was established. One important consideration in this decision was the fact that the effects on detailed instrument and laboratory requirements could be studied and identified with much greater clarity when analyzed in relation to well defined, specific experimental procedures. The decision to proceed in this manner required identification of both biological and environmental experiments that would be representative of the classes of experiments likely to be employed in early- to mid-1970 Voyager missions. That is, a complement of experiments was needed which require instrumentation and processing capabilities representative of the majority of engineering problems likely to be encountered in the ABL. The selection of these experiments, and resulting instrument complement took place in two distinct steps during the course of the present study.

Initially, Aeronutronic performed evaluations of candidate experiments and instruments from a wide range of sources, utilizing evaluation procedures developed specifically for this task. The results of the evaluation of the biological experiments considered in this analysis are discussed in the remaining portion of this section (3). In the following section (4), the comparable analysis performed by Aeronutronic of environmental experiments is covered.

Following and concurrently with these analyses by Aeronutronic personnel, review and analysis of these same, and additional, experiments was underway by members of the Bioscience Subcommittee of the National Academy of Science, and other informal consultive and working groups from the scientific community and NASA. Recommendations from these groups were correlated with the results of Aeronutronic's own analyses and the resulting complement adopted for use in the ABL preliminary design study. The resulting experiment and instrument complements are identified and described in detail in the remaining sections of this volume and their related appendices in Volume VI.

3.2 METHODS OF ANALYSIS OF BIOLOGICAL EXPERIMENTS

3.2.1 SOURCES OF INFORMATION

No defined experimental complement appropriate for accomplishing the above objectives had been suggested prior to this study and the information necessary to define such a complement was not available in an organized form. Therefore, it was first necessary to gather the data which would be useful for selecting the experimental complement. The most desirable information appeared to be: (a) a comprehensive list of suggested life-detection experiments and (b) for each experiment, the attribute of life demonstrated, the specific information obtained, and the factors affecting the experiment's reliability, sensitivity, and compatibility with other experiments and the capsule environment. This information was obtained by the following methods:

(1) The life detection experiments under development for NASA were reviewed.

(2) Scientists who were interviewed (see Section 2 and Appendix 1, Volume VI) suggested and described specific experiments.

(3) The information obtained at the NAS Space Science Board's Summer Study on Exobiology at Stanford University was analyzed.

(4) Specific experiments and analytical instruments were discussed with scientists at the Jet Propulsion Laboratory and NASA-Ames Research Center.

(5) The information gained by attending NAS Bioscience Subcommittee meetings was analyzed.

(6) A search of the literature was conducted by the Aeronutronic bioscience staff.

3.2.2 METHODS OF INFORMATION ANALYSIS

Experiments suggested or implied by the information obtained were given short titles to identify them. On the basis of the primary attribute of life demonstrated, each experiment was then placed in one of the categories listed in Table 2-III. From these experiments an appropriate life-detection complement was formulated by rating the experiments and selecting them on the basis of the scores achieved. The rating system devised to accomplish this task is presented in Table 3-I.

TABLE 3-I

RATIONALE OF RATING LIFE DETECTION TECHNIQUES

	Rating Parameter	Weighting Factor		Pertinent Information or Factors Considered	Maximum Score
A.	Likelihood that sample contains substance or will perform function sought	0.7	a.	Is the distribution of the biological entity such that the sampling procedure is adequate?	2
			b.	Is the function or substance one which always occurs in terrestrial life?	2
			c.	Can the function, reaction or material be observed without the use of preselected specific chemicals?	2
			d.	Is it extremely unlikely that the substance or function can be replaced by a different substance or function?	2
			e.	Is it difficult to abiogenically produce or imitate the substance or function?	2

TABLE 3-I (Continued)

	Rating Parameter	Weighting Factor		Pertinent Information or Factors Considered	Maximum Score
B.	Probability that test characteristic applies to Martian life	0.7	a.	Does the nature of the test depend upon a property of the substance or function which is necessary for biological function?	2.5
			b.	Is the test function or substance a biologically valuable property?	2.5
			c.	Does the technique test all possible mechanisms or situations in a multiple array of processes and circumstances?	2.5
			d.	Is it unlikely that the substance can be replaced by another compound or that the function can be accomplished by a different mechanism?	2.5
C.	Lack of ambiguity of the result	1.0	a.	Does the technique give a positive result only for the property or substance sought?	5
			b.	Are false-positive or negative results due to small changes in environmental parameters extremely unlikely?	5
D.	Independence of test procedure from biological richness of sample and separating procedures	0.7	a.	Can the test be conducted without separating the biological entity from other substances?	4
			b.	Would the test substance be expected to represent a large percentage of an organism and would a function be expected to proceed at an easily detectable rate?	3

TABLE 3-I (Continued)

Rating Parameter	Weighting Factor		Pertinent Information or Factors Considered	Maximum Score
		c.	Is a physiological change in an organism unnecessary for the test procedure?	3
E. Independence of characteristic on time constant	0.7	a.	Is the frequency of the function or event such that it can be observed in a reasonable time period?	2.5
		b.	Is the sensitivity of the method such that it will detect a limited number of events?	2.5
		c.	Can the experiment be designed to take advantage of an accumulation of events over a time period to increase sensitivity?	2.5
		d.	Can the characteristic or substance be observed in a static system?	2.5
F. Compatibility of substance or function with estimated Martian environment	0.4	a.	Is the estimated Martian atmospheric composition compatible with the existence of the function or substance?	5
		b.	Are the estimated Martian temperatures favorable to the existence of the substance or process?	5

3.2.3 DESCRIPTION OF RATING SYSTEM

The rating system devised consists of rating parameters, weighting factors, pertinent information or factors considered, and a scoring method. The goals and the specific constraints for each of these items are outlined below:

a. Rating Parameters. The rating parameters define areas which can be used to evaluate the experiments as to the probability of their success and the meaningfulness of the information obtained. These parameters, together with the factors upon which they depend, are:

(1) Likelihood that sample contains substance or will perform function sought.

(a) The likely distribution of the entity both geographically and biologically.

(b) The degree to which it is necessary, in order to obtain a successful test, for the Martian entity to react or perform in a manner analogous to its terrestrial counterpart.

(c) The possibility that the function or substance is not necessary for Martian life.

(d) The ease with which the function or substance can be imitated by abiogenic processes.

(2) Probability that test characteristic applies to Martian life.

(a) The biological necessity of the function or substance.

(b) The relevance of the test to detection of the biologically critical structure in a substance or the overall result of a function.

(3) Lack of ambiguity of the result.

(a) The specificity of the technique.

(b) The stability of testing procedure.

(4) Independence of test procedures from biological richness of sample and separating procedures.

(a) The sensitivity of the method employed and the expected unit cellular content of the substance or activity of the function sought.

(b) The purity of the material required to conduct the test.

(c) The necessity of requiring a biological amplifying process or an organism controlled act.

(d) The independence of the test procedure from the need for separating the biological entity from the materials.

(5) Independence of characteristic on a time constant.

(a) Probable frequency of an event and the necessity for a dynamic system.

(b) Sensitivity of the method employed.

(6) Compatibility of substance or function with estimated Martian environment.

(a) The possible influence of the Martian atmospheric composition and temperatures on the existence of a substance or function.

b. Weighting Factor. Weighting factors are assigned on the basis of the likelihood that the parameter accurately assesses the Martian situation. For our system this was accomplished by determining if: (1) terrestrial biological data were assumed to fit the Martian situation and (2) Martian environmental conditions were assumed to influence the experimental technique or affect the substance or function sought. If either (1) or (2) were involved, the weight for the parameter was reduced 30 percent and if both (1) and (2) were involved it was reduced 60 percent.

c. Pertinent Information or Factors Considered. To be able to apply the rating system in a uniform manner, a standard set of questions was devised for use in exploring the rating parameters. These questions were phrased so that a yes answer was a favorable response.

d. Scoring. Each rating parameter in Table 3-I was assigned a non-weighted value of 10. In each case, except for D-a, the questions were

considered to be of equal importance and, therefore, they received equal shares of the total score. Question D-a was considered to be more important than the other questions for parameter D, because it relates to the need for separating the biological entity from other substances and also to the purity of the material required for the test. (These two factors are often different, since even if the organisms are separated from other materials, it may be necessary to then purify components of the organism.)

The scores given for questions D-b and E-b require some additional explanation. These questions are essentially the same, since they are concerned with the sensitivities of the techniques and the expected cellular concentrations or reaction rates for the substances or functions sought. To rate the techniques in regard to sensitivity, it was necessary to devise a common base for evaluation. This was done by expressing the sensitivities in terms of the number of organisms required to produce a positive result. However, this method considers only the expected cell population. It does not take into account the possibility that substances, such as porphyrins and lipids, may accumulate in the soil and therefore be present in the sample in amounts vastly greater than their concentrations in the living cell. Nevertheless, the method appears to be useful as a first approximation. The calculations used to arrive at the sensitivities were based on experimental values given in the literature rather than on theoretical considerations and they are presented in Appendix 2, Vol. VI. After the number of cells required for each technique was determined, weighting factors from 1 to 0 were assigned as follows:

No. of Cells	Weighting Factor	No. of Cells	Weighting Factor
10^2	1.0	10^7	0.5
10^3	0.9	10^8	0.4
10^4	0.8	10^9	0.3
10^5	0.7	10^{10}	0.2
10^6	0.6	10^{11}	0.1

The maximum scores for questions D-b and E-b were then multiplied by the weighting factor to arrive at the scores for these questions.

A total score for each parameter was obtained by adding the scores which the questions received. This total score was multiplied by the assigned weighting factor and a weighted score obtained. The weighted scores were added to produce a total weighted score.

3.3 RESULTS

The experiments which were considered are arranged in Table 3-II according to the attribute of life demonstrated. In addition, the calculated

TABLE 3-II

SUMMARY OF LIFE DETECTION TECHNIQUE EVALUATION

No.	Technique Name	Calculated Sensitivity (Minimum No. of Cells Required)	Total Rating Score	Rank (Within Category)
I.	**Energy Transfer and Conversion**			
1.	Evolution of Heat	2.9×10^7 (Dividing Cells)	24.5	8
2.	Change in Heat Content	1×10^6	23.2	11
3.	Light Emission	5.4×10^3	19.9	20
4.	Unpaired Electrons	10^9 (Dying Cells)	17.5	24
5.	Bioelectric Potential	1.3×10^9	21.2	17
6.	Conversion of C^{14} Labeled Substrates to $C^{14}O_2$	7.5×10^3	26.9	5
7.	Dark Fixation of $C^{14}O_2$	2.5×10^2	28.0	3
8.	Light Stimulated Fixation of $C^{14}O_2$	4	27.0	4
	Detection of ATP			
9.	Enzymic	1.2×10^5	28.2	1
10.	Chemical	1.2×10^{10}	22.4	13
11.	Ion Exchange	6×10^9	26.0	6
	Light Stimulated Evolution of Oxygen			
12.	Tracer (O^{18})	45	21.5	16
13.	Cartesian Diver	22	19.9	20
14.	Microrespirometry	2.2×10^3	19.4	22
15.	Oxygen Electrode	2.2×10^5	18.7	23
16.	Magnetic Susceptibility	9×10^3	22.2	14

TABLE 3-II (Continued)

No.	Technique Name	Calculated Sensitivity (Minimum No. of Cells Required)	Total Rating Score	Rank (Within Category)
	Oxygen Uptake			
17.	Cartesian Diver	1.5×10^3	21.0	18
18.	Microrespirometry	1.5×10^4	20.7	19
19.	Oxygen Electrode	1.5×10^7	15.7	25
20.	Magnetic Susceptibility	6×10^5	22.0	15
	Carbon Dioxide Evolution			
21.	Change in Conductivity	1.5×10^7	28.1	2
22.	Cartesian Diver	1.5×10^4	24.2	9
23.	Microrespirometry	1.5×10^5	23.7	10
24.	CO_2 Electrode	1.1×10^8	22.9	12
25.	Piezoelectric Crystal	7.5×10^3	26.0	6
IIA.	Detection of Specific Macromolecules			
	UV Spectrophotometry			
1.	DNA	2×10^7	30.2	3
2.	Protein 280 mμ	1.2×10^7	23.5	12
3.	Protein 190 mμ	1×10^6	29.5	5
	Visible Spectrophotometry			
4.	Protein	5×10^4	27.7	10
5.	DNA	1×10^7	29.0	7

TABLE 3-II (Continued)

No.	Technique Name	Calculated Sensitivity (Minimum No. of Cells Required)	Total Rating Score	Rank (Within Category)
	Optical Rotation			
6.	DNA	5×10^8	22.0	14
7.	Protein	7×10^6	25.6	9
8.	Dye - DNA Complex	5×10^8	22.1	13
	Other			
9.	Refractive Index	2.2×10^7	24.0	11
10.	Viscosity DNA	4×10^8	*	
11.	Colorimetry	1×10^6	28.8	8
IIB.	Detection of Macromolecules in General			
1.	UV Spectrophotometry	1×10^6	33.4	2
2.	Optical Rotation	7×10^6	29.6	4
3.	Visible Spectrophotometry	5×10^4	33.7	1
4.	Optical Rotation Dye - Macromolecule Complex	7×10^6	29.2	6
III.	Reproduction, Replication and Growth			
1.	Turbidity Increase	1×10^5	18.8	18
	Weight Increase			
2.	Balance	3.3×10^6	18.2	19
3.	Piezoelectric Crystal	1×10^5	20.2	16

* See Appendix 2, Volume VI

TABLE 3-II (Continued)

No.	Technique Name	Calculated Sensitivity (Minimum No. of Cells Required)	Total Rating Score	Rank (Within Category)
	Macromolecule Increase			
4.	Dye Absorbance	5×10^4	24.7	1
5.	Optical Rotation	5×10^8	24.2	3
6.	UV Absorbance	1×10^6	23.7	6
	Nucleic Acid Increase			
7.	UV Absorbance	5×10^6	15.8	20
8.	Colorimetry	2×10^8	14.6	21
	Protein Increase			
9.	UV Absorbance 280 mμ	1.2×10^7	19.7	17
10.	UV Absorbance 190 mμ	1×10^6	24.3	2
11.	Colorimetry (Lowry)	1×10^6	24.1	4
	Increase in Complex Lipids			
12.	Gas Chromatograph with Mass Spectrometer Detector	5.2×10^7	23.8	5
13.	Infrared Spectrophotometry	3.3×10^{10}	20.9	14
14.	Optical Rotation	5.2×10^{11}	20.5	15
15.	Colorimetry	2.5×10^9	21.8	12
16.	Mass Spectrometry	5.2×10^7	22.0	9
	Fatty Acid Increase			
17.	Gas Chromatograph with Mass Spectrometer Detector	1×10^6	23.1	7
18.	Mass Spectrometer	1×10^6	23.1	7

TABLE 3-II (Continued)

No.	Technique Name	Calculated Sensitivity (Minimum No. of Cells Required)	Total Rating Score	Rank (Within Category)
19.	Infrared Spectrophotometry	1×10^9	22.0	9
20.	Colorimetry	2.5×10^9	21.8	12
21.	Increase in Phospholipid Phosphate by Colorimetry	3.6×10^6	21.9	11
IV.	Detection of Unique Substances Associated with Living Systems (Exclusive of Macromolecules)			
	Amino Acids			
1.	Gas Chromatography with Mass Spectrometer Detector	1.6×10^5	33.5	1
2.	Mass Spectrometer	1.6×10^5	28.3	11
3.	Ninhydrin	5×10^5	33.3	2
4.	Purine and Pyrimidine Bases by UV Absorbence	4×10^6	29.9	8
	Carbohydrates			
5.	Gas Chromatograph with Mass Spectrometer Detector	1.6×10^5	27.5	12
6.	Mass Spectrometer	1.6×10^5	22.5	13
7.	Colorimetric	8×10^7	20.0	14
	Detection of Porphyrins by Fluorimetry			
8a.	Photosynthetic Pigments Only	5×10^4	28.9	10
8b.	Porphyrins Other than Photosynthetic	4×10^7	31.6	4
9.	Detection of Fatty Acids by Gas Chromatography with Mass Spectrometer Detector	1×10^6	33.1	3

TABLE 3-II (Continued)

No.	Technique Name	Calculated Sensitivity (Minimum No. of Cells Required)	Total Rating Score	Rank (Within Category)
10.	Detection of Non-saponifiable Lipids by Gas Chromatography with Mass Spectrometer Detector	5.2×10^7	30.3	7
11.	Detection of Phospholipid Phosphorus	3.6×10^6	29.4	9
12.	Detection of Total Flavins by Fluorometry	2.5×10^6	31.2	6
V.	Detection of Catalytic Activity			
1.	Detection of Dehydrogenases	4.5×10^9	18.9	3
2.	Phosphatase by Fluorometry	5.3×10^3	23.2	2
3.	Catalase by Microspirometry	1.2×10^2	15.0	4
4.	Oxygen Exchange between O^{18} Labeled Oxyanions and Water by Mass Spectrometry	1×10^9	23.3	1
VI.	Detection of Organization			
1.	Optical Purity by Polarimetry	1×10^7	35.5	1
2.	Macroscopic Observations	2.5×10^3	23.1	2
3.	Macroscopic Observations	3×10^4	21.2	3

TABLE 3-III

SELECTED REPRESENTATIVE EXPERIMENTS
FROM THE RANKED LIST

I Energy Transfer and Conversion

- A. Carbon Dioxide Evolution and Fixation
  1. Light-stimulated $C^{14}O_2$ Fixation and Dark $C^{14}O_2$ Fixation
  2. Evolution of CO_2 by In Situ Metabolism
  3. $C^{14}O_2$ Uptake in Light and Dark and Subsequent Evolution by Metabolism

II Macromolecule Detection

- A. UV Spectrophotometry
- B. Visible Spectrophotometry

III Replication and Reproduction

- A. Macromolecule Increase with Time
- B. Increase of Complex Lipids with Time

IV Detection of Substances Associated with Terrestrial Life

- A. Gas Chromatograph with Mass Spectrometer Detector
  1. Detection of Steroids and Complex, Nonsaponifiable Lipids
  2. Detection of Fatty Acids
  3. Amino Acid Analysis by Volatile Derivitives
  4. Amino Acid Analysis by Pyrolysis-Gas Chromatography
- B. Fluorometric Analysis
  1. Porphyrins
  2. Flavins

V Specific Enzymic Function

- A. Exchange of O^{18} from Oxyanions with H_2O

VI Evidence for Organization

- A. Visual Inspection
- B. Analysis for Optical Purity

sensitivity of each experiment and its rating score and rank within the category are indicated. A detailed evaluation of each experiment and the computation of the sensitivity of each technique are recorded in Appendix 2, Volume VI.

As a constraint on the number of experiments selected and to prevent the payload from becoming overly oriented towards one approach, two experiments were selected from each category. The highest scoring experiment in each category was always selected and the next highest scoring distinctively different experiment was designated as the second experiment. For example, in the detection of replication and reproduction category the four highest ranked experiments all detect increases in macromolecule concentration with time. Thus, the fifth ranked experiment was picked as the second experiment in this category. The experiments selected are listed in Table 3-III and brief outlines of possible procedures for accomplishing the experiments are presented at the end of Appendix 3, Volume VI.

3.4 DISCUSSION

The experiments which were considered in this analysis are obviously not the only ones possible. Furthermore, it is recognized that the assignment of an experiment to a particular category is, in some cases, arbitrary because many experiments demonstrate independently more than one attribute of life, or the phenomenon or substance considered may be an important aspect of several attributes. Finally, although in many cases different methods of accomplishing the same experiment were presented, time did not permit consideration of all the variations possible for a particular method. Nevertheless, the experiments considered are representative of the majority of experiments recommended by the various sources consulted.

Of the nine properties of life most often considered by scientists, only six appear in the above analyses. Ability to mutate and to respond to stimuli do not appear, because no experiments have been suggested to demonstrate mutation, and irritability was not considered by many scientists to be necessary for life. The necessity for an aqueous environment does not appear, because this was considered to be an environmental experiment. In this regard, it should be kept in mind that there are certain environmental measurements which are difficult to distinguish from life detection experiments. For example, chemical analyses of a general survey type (e.g., elemental soil analyses and analyses for organic carbon) and the detection of liquid water have been considered in this study as environmental measurements. Others may consider such measurements to be life detection experiments with equal justification.

The rating system devised for use in this study is based largely on assessing the biological value of the experiments rather than advantages derived from

the instruments used. This was done because instruments and new techniques are being rapidly and continually developed, whereas the biological significance of the data changes, if at all, slowly. Although the rating system was intended solely to select a sample life detection complement for use in the preliminary engineering design of the ABL, it should be possible to apply this system, or a similar one, for rigorously screening other potential life detection experiments.

SECTION 4

DEFINITION OF ENVIRONMENTAL EXPERIMENTS

4.1 INTRODUCTION

To achieve the goals previously defined for the ABL, selected environmental measurements also must be conducted, in addition to the biological experimentation. The nature of the bioenvironment, especially particular aspects of it, such as water availability and soil salinity, are extremely important. The following sections consider a variety of meaningful environmental measurements, some of which are subsequently recommended for the ABL. A comprehensive listing of experiments is considered which is then narrowed to those which will directly support the biological objectives or overlap with biological experiments; that is, borderline experiments which may be considered either biological or environment measurements.

4.2 OBJECTIVES AND CONSTRAINTS

The specific objectives of this analysis were to:

(1) Identify environmental measurements which are appropriate to the ABL mission.

(2) Evaluate the resulting experiments in terms of specific criteria and constraints (which will be defined below).

(3) Select a representative complement of environmental experiments.

(4) Define the instrumentation needed to obtain the specified experimental data for purposes of performing the ABL preliminary design and feasibility studies.

Essentially no up-dating of the current estimates of the Martian environment prior to the ABL mission were assumed in this study. Most of the desired environmental information for the ABL must be gathered at the time and site of the ABL sampling operations in any case. A high correlation between environmental measurements and biological experiment results is essential in most cases and can be obtained only if the two kinds of measurements are coincident in time and location. Prior environmental measurements may have important repercussions on the lander, and therefore the payload weight available to the ABL, but are not expected to affect the ABL itself in a significant way.

The range of possible experiments for planetary exploration is practically unlimited. Therefore the environmental experiments were limited to those important to a biological mission. Suggested candidate environmental experiments had to satisfy at least one of the following criteria:

(1) Provide ecological information and characterize Martian biota in terms of their interaction with the environment. Biologically significant environmental information and even information indicating the possible existence of life should be obtained. There may be considerable overlapping of environmental and biological experiments, as already discussed. An environment experiment may contribute directly to detection, identification, or classification in a biological experiment.

(2) Aid the interpretation of biological experimental results. Such information as location where sample was gathered, moisture content, salinity, and temperature will be helpful, and in some cases mandatory, in interpreting the results of various biology experiments. As another example, if the subsurface is found to be hard or rock, then it would be reasonable that the subsurface samples should be found devoid of indications of life.

(3) Indicate appropriate experimental procedures where prior knowledge was not sufficient to provide adequate specifications. The integrated laboratory permits such changes or corrections in procedures as a result of new information. For example, measurements of the soil salinity (identities and amounts of water soluble, inorganic ions) would provide data needed to make osmolarity adjustments of culture media. In the dialysis of soil water extracts to separate macromolecules and salts, a knowledge of the amount of salt present would indicate the extent of dialysis required.

Environmental measurements not in some way applicable to a biological mission are excluded. Also, measurements made during the descent are excluded for consideration since the ABL is considered to function in a experimental mode only after being deployed on the surface. This does not mean that such experiments are undesirable, but simply that they were beyond the scope of the present study.

An exceedingly important advantage accruing to an ABL which includes the capability to perform environmental measurements is that in the event life is not found or if biologically interesting activity is of a low order, the mission may be switched to a mode of performing predominantly environment experiments. Information of high scientific value can continue to be obtained and what would otherwise be a mission failure can be prevented.

In addition, environmental experiments can also shed light upon some of the broader scientific objectives discussed in Section 2 if life is not found. For example, environmental clues to the questions of why development of life was prevented, or whether life had existed but declined and failed, could be obtained.

4.3 TECHNICAL DISCUSSION

The categories of experiments useful in support of a predominantly biological mission are:

(1) Atmospheric and meteorological measurements

(2) Solar insolation and spectrum

(3) Ionizing radiation

(4) Surface and subsurface physical properties

(5) Soil chemical properties

(6) Visual and infrared imaging and scans

4.3.1 ATMOSPHERIC AND METEOROLOGIC MEASUREMENTS

a. Static and Dynamic Atmospheric Pressure at the Surface. Virtually all the explanations for observed phenomena, the theoretical studies of the Martian atmosphere, and engineering designs are tentative until the mean surface pressure is known. Moreover, short term, diurnal and seasonal barometric changes are important. The geostrophic winds are driven by pressure gradients. Estimates of cyclonic intensity depend on the pressure change to average pressure ratio.(1) The possibility for phase changes is determined by the relative values of ambient pressure and vapor pressure.(2) The static surface pressure of the atmosphere when coupled with other atmospheric measurements (temperature and composition) will provide information about the state and amount of water in the atmosphere and in the surface soil in equilibrium with the atmosphere. Temporal changes in static pressure can be related to Martian meteorology and perhaps seasonal changes. Current knowledge (preliminary findings of the Mariner IV occultation experiment) indicates the surface pressure to be between 10 mb and 20 mb. The dynamic pressure is of interest in regard to magnitudes and directions of surface winds and the possibility for material transport via the winds. If considerable material is carried by winds, surface life forms must be adapted to such conditions. Transport of indigenous and contaminating terrestrial life forms on the winds may be possible.

Both static and dynamic pressure in the pressure ranges of interest for Mars may be measured with a pitot tube connected to an aneroid bellows. Also, at the expected low ambient pressure a hypsometer (which measures pressures by rate of evaporation of a liquid) could be used for the static pressure measurement. The Havens cycle gage is another possible pressure measuring instrument for Mars since it can monitor a wide range of pressures from as low as 10^{-5} mb to as high as 10^{3} mb.(3) The Havens cycle gage is a modification of the Pirani gage which itself may be used up to pressure of about 4 mb.

Since the expected pressure is low (on the order of 10 mb), small changes must be measured since they may reflect major changes in meteorological phenomena. Changes of about 0.1 mb may be significant. Especially in the equatorial areas, meteorologically-induced pressure tendencies may be masked by the diurnal pressure wave due to the excess of diurnal variation of temperature in the layer of air over the surface.(4)

b. Wind Velocity and Direction. The selection and removal of dust, sand, and biological materials from the surface is determined by the microscale wind regime. If considerable material is carred by winds,

surface life forms must be adapted to covering or eroding by such material. Transport and distribution of life forms on the winds becomes a possibility, and the occurrence of notable winds would support arguments for wide distribution of light and small forms of life. Winds also have an important bearing on the extent of spreading over the planet of accidental contamination with terrestrial life or organic residues of such life.

The physical properties of the wind and the wind velocity specify the limits of particles to be transported.(5) In turn, in the surface layer, the composition of the soil and its roughness characteristics may alter the winds. Measurement of the wind at locations vertically spaced will outline the wind profile for the lowest layer of the atmosphere and afford an insight into the surface properties.

Wind velocity and direction should be recorded at intervals during the diurnal cycle, the seasonal cycle, and during varied weather conditions. If serious erosion is found due to wind transported sand, it may be desirable to monitor the wind at all times. If the wind velocity exceeds a preset maximum, the laboratory could be programmed to take protective measures to avoid damage to sensitive equipment.

Measurements may be obtained with hotwire anemometers oriented to yield the two horizontal wind components. Hourly reports to the nearest 10 ft/sec . and to within 30° will suffice for normal conditions. Wind speeds at the 6-foot level and above are expected to be generally below 200 ft/sec.. However, for transport it is the individual gusts which are of importance, especially in the surface layer. A compromise assembly would measure a rather long term average at the 6-foot level and only significant gusts at lower positions.

Some useful redundancy of information will result from wind measurements which can be used as checks against other experiments. From a measurement of static pressure, temperature, and mean atmospheric molecular weight (composition), the atmospheric density can be determined. This together with the dynamic pressure measurement will provide a check on wind velocity measurements at high velocities.

Viscosity and density of the atmosphere are important in determining the capability of Martian winds to carry dust and small particulate material. The viscosity and density can be estimated from measurements of atmospheric temperature, pressure, and composition. Predictions of wind transported material quantities, densities, and sizes can be compared with actual measurement of material transport as described below.

c. Atmospheric Temperature. The temperature of the atmosphere at all altitudes is of interest in determining meteorological parameters which can affect biology. For the ABL mission a measurement of the air

temperature at the surface alone will suffice. Such a temperature measurement is useful in determining aqueous water availability. Air temperature data is also needed to estimate atmospheric density and viscosity. Variations of temperature from day to night will indicate the rate of thermal loss to space through the thin atmosphere. Heat conduction by the atmosphere can be important to surface life forms exposed to the extremes of direct sun and cold nights.

Temperature measurements for Mars heretofore have been strictly for the ground. Meteorologically, the near surface (within 6 feet) air temperature is more meaningful and required. Terrestrial experience suggests that a severe drop of temperature occurs within even the first few millimeters.(6) Purely radiative considerations indeed portray a sharp decrease very near the surface. However, the resulting superadiabatic lapse rate cannot long endure. Vertical motion occurs and establishes an adiabatic lapse throughout most of the troposphere. The exact profile is determined by the total insolation (diffuse and direct), the net flux of ground radiation, latent heat transfer, heat conducted within the soil to or from the surface, and the transport of heat by turbulence in the air.

In any case, the daytime lapse rate near the surface is expected to be severe; at 6 feet the air temperature may be some 50°C lower than the radiometrically determined ground temperatures.(6) Moreover, observations and theory warn of a diurnal variation of 100°C near the equator. The 6-foot variation may be somewhat less, however, with a consequent inversion occurring near sunrise. An hourly report from thermistors located vertically along a boom would define the diurnal rhythm of temperature. Furthermore, from the phase lag in maxima and minima and its variation with height, and from the vertical change of amplitude, the primary mechanisms for thermal balance in the microscale would be delineated.

d. Atmospheric Composition. The primary constituents of the Martian atmosphere are assumed to be CO_2 and N_2 or A. Many trace components have been suspected and sought (O_2, O_3, H_2O, NO_2). Recent studies place the pressure of water vapor between 5×10^{-4} and 1.5×10^{-3} g/cm^2.(7) Observations have suggested phase changes or chemical alterations occur diurnally. For example, the veil on the morning terminator may be dew or fog; but doubts persist.(6) The possibly intense ultraviolet radiation at the surface may be an effective mechanism for the diurnal variation of trace components. Rather than a single determination of composition then, a series of tests should be made during the diurnal cycle. The identities and partial pressures of the primary atmospheric gaseous components such as CO_2, N_2, and A and trace components such as O_2, H_2O, H_2S, CO, SO_2, NH_3, O_3, CH_4, NO_2, and NO are of interest in the biological exploration of Mars.(8,9) Most of the gases may be directly involved in biochemical processes. Argon is of interest since its presence in any substantial quantities implies

volcanism (from volcanoes to small hot springs) which might also have released water vapor (defluidization).[8] Although water may not be present in any but traces at present, in the past it may have had a higher partial pressure.

Instrumentation capable of measuring the variety of gases listed above include the gas chromatograph (multiple columns) and a gas source mass spectrometer. The mass spectrometer may be used in tandem with the gas chromatograph. Complementary data from the gas chromatograph (retention times or volumes and peak magnitudes) and from the mass spectrometer (mass of peak component or components and relative concentrations or partial pressures) can be extremely valuable in achieving precise identification of an unknown gas.

The atmospheric composition should also be compared with subsoil gas composition. Differences in some components can be indicative of biochemical action in the soil.

Water is of such importance to life that the determination of atmospheric water warrants a sensitive specific detector (see e. Atmospheric Humidity below). Oxygen is another constituent very important to terrestrial life and may also be required by Martian life. A specific gas sensor for oxygen which may be used is copper impregnated with a radioactive isotope of krypton. The copper releases the krypton when heated at a rate dependent upon the partial pressure of atmospheric oxygen.[10]

It is possible to use alpha scattering and alpha, proton reactions to measure the primary constituents N_2, A, and CO_2.[11] The technique is probably too specific, and does not analyze for all the gases of interest to ABL experiments.

e. Atmospheric Humidity. Water vapor is of such importance to life that it may warrant a separate sensor for its sensitive measurement.[9] Such a sensor may be a gold film/aluminum oxide wafer.[10] The resistance of the wafer changes with the quantity of absorbed water in the aluminum oxide. Reported sensitivities are as low as 10^{-5} Torr partial pressure of water. This device could also be included in a subsurface probe to detect soil moisture. The humidity would be monitored at intervals during the diurnal cycle, the seasonal cycle, and during varied weather conditions.

Local microenvironments having relatively high water vapor partial pressures might be detectable with an infrared radiometer operating in several wavelength bands selected to permit discrimination of thermal sources and water vapor sources. The radiometer would scan the surroundings at a low resolution up to and including the horizon. Such a radiometer would provide additional data on the local thermal variations.

f. Dust and Airborne Particles. Winds sweeping over the apparently arid Martian deserts could very well generate dust storms and foster

dune formation. In the absence of water, the action of wind-blown particles could be the major factor in erosion. In addition, life forms would need to adapt to such unsettled conditions as repeated burial and removal of supporting soil. An assessment of the quantity and size distribution of wind-borne matter would bear on the biology as well as the geology of Mars.

The amount and kinds of coarse material transported by wind action could be determined as a function of height and wind velocity. The collectors may consist of a series of sticky tapes or cups spaced vertically on a mast. After a predetermined interval of time these would be retrieved and examined (weighed or placed in view of the imaging system). There also exists the possibility of using the collected material as samples in life detection experiments.

The fine- and light-weight air-borne constituents could be collected and detected by use of an airpump and an impaction plate or filter. Impaction on a plate or filter would afford a simple index to the intensity of aeolian activity. Inorganic components such as dust, sand, and powder and organic components such as spores, pollen, microorganisms, biological material and debris could be collected. The collected material could then be inspected with microscopy or subjected to further experimentation (chemical analysis, growth). The distribution of particles of different sizes with height would measure the intensity and load capabilities of the winds.

A third and less elaborate mechanism for determining wind transported particles is to use impingement of them upon a resonator/microphone.

g. Visual Scan of the Sky. Visual scans of sky can determine the extent of cloud cover, haze, dust, storms, and gross atmospheric transmissivity and sky brightness. Such meteorological phenomena may affect life through its influence of the planetary heat balance, large scale transportation of dust, spores, and other particulate matter, and transport of water. Intense storms may move enough granular surface material to bury life forms in dunes or remove supporting soil. The sky scan will also indicate the number and size of clouds (dust or haze) and may detect other meteorological occurrences such as electrical discharges and storms in the atmosphere.

h. Infrared Radiometer Scans of the Sky. The thermal structure of sky can be examined using a scanning infrared radiometer. Correlations with the visual scans would be useful in determining the nature of clouds and storms.

i. Cloud Composition. If visual inspection of the sky reveals a cloud formation, the cloud may be further investigated to ascertain its

composition (particulate size distribution and chemical composition). This information can be inferred from the differential spectrum of light transmitted or reflected from the cloud and the light from a clear region of the sky. For example, if the sun is observed directly and its spectrum recorded, then a cloud passing between the sensor (spectroradiometer) and the sun will produce a differential spectrum which will provide indications of cloud composition. Similar techniques may be applicable during dust storms and other atmospheric phenomena. The equipment required is identical to that used to obtain the solar spectrum.

4.3.2 SOLAR RADIATION EXPERIMENTS

The experiments on solar radiation cover the wavelength regions from far infrared to far ultraviolet.

The spectral irradiance of sunlight at the surface of Mars is biologically interesting. The ultraviolet irradiance in particular may have profound effects on possible life. Because of the very thin atmosphere, surface life may have to tolerate what in terrestrial experience would be considered a damaging ultraviolet flux. Adaptation to such conditions is, of course, quite possible but may take unique forms. The protective mechanism might, for example, take the form of a thick waxy coating or a special cell wall chemical composition. Another adaptive mechanism might be for life to exist mainly below the surface or covered with sand particles and debris. Such life might not be evident in visual scans of the Martian surface.

The chemical composition of the atmosphere is currently poorly known. Some atmospheric constituents may reduce the ultraviolet flux at the surface through absorption or scattering processes. A measurement of the spectrum of the solar ultraviolet will provide additional information about the atmospheric composition and chemical reactions in the atmosphere.

A candidate biological experiment for the ABL is detection of light stimulated chemical process and energy conversion which will serve as a test for the occurrence of photosynthesis. For example, light dependent carbon dioxide fixation might be measured. A backup environmental experiment would be a measurement of the available energy for photosynthesis in the visible region. Again in the case of the visible spectrum taken at the surface viewing the sun can provide information about atmospheric components. Additional data on the presence and amount of oxygen (7500 Å) could be obtained from a comparison of the zero air mass solar spectrum and the surface spectrum.

In the infrared region, the solar irradiance is important as a source of heat. The spectrum may also indicate the presence and amount of water vapor or carbon dioxide.

Of all the possible solar irradiance measurements in spectral regions, a gross measurement of the ultraviolet flux from about 185 to 300 mμ was considered of primary interest by the ad hoc Bioscience Work Group.[9] A sensor having 2π steradian field of view directed vertically could give an integrated value of direct and scattered ultrviolet flux including the sun at all times during daylight. Rough spectral resolving power is desired (say from 10 to 100 mμ bandwidths) which can be achieved using filters and multiple sensors.

Alternately the ultraviolet and visible spectrometer and the infrared spectrometer used in biochemical experiments might be adaptable for determination of the solar spectrum with slight modification. Additional optics would be required to focus the sun's image on the entrance slit of the spectrometer. A sun seeker would acquire the sun, and a simple servo guidance system can maintain the image on the slit during measurement. Such measurements would produce considerably more data than the broadband radiometer sensor described above.

Sky brightness in the visible region can be determined using a simple photometer, such as the Model 856 Weston Photronic cell with a selenium light sensitive element. A lead sulfide detector with the appropriate filter can be used to determine the sky brightness in the infrared region. The imaging system can provide an alternate indication of sky brightness if a scan of the sky is programmed.

4.3.3 IONIZING RADIATION EXPERIMENTS

The radiation environment will consist of natural and induced radioactivity of surface crustal materials, primary cosmic radiation including high energy solar particles, and secondary radiation which is generated in the Martian atmosphere. Because of the absence of the shielding effects due to the negligible planetary magnetic field and low atmospheric mass, the radiation at the surface may be one or more orders of magnitude greater than the levels experienced on Earth. The identity, intensity, energy spectrum, and time variation of the radiation environment is of considerable radio-biological interest because the expected somewhat higher levels may require special adaptive measures to prevent excessive lethal gene mutations and chromosome aberations from occurring.

A thorough measurement of the various possible radiations and their spectra requires that several detectors be employed. Three types of detectors, each covering part of the energy range of interest, are a solid state telescope, Cerenkov counter, and scintillation counter. In the event that sufficient weight is not available for all three instruments, a very rough measure of the radiation background can be made using one or two proportional counters and pulse height analysis to provide some energy resolution. Such a minimal measurement is essential

to the interpretation of results from those experiments which employ radiation sensors or are sensitive to variable radiation levels. The experiment would further provide geologically useful data as to the abundance of uranium and thorium in crustal materials. The extent and mechanisms of Martian crustal differentiation would be indicated. Proportional counters appropriately shielded and perhaps employment of coincidence techniques would enable a distinction to be made between surface radiation and cosmic radiation sources. The shielded sensor assembly could be rotated to face upward or toward the surface when desired. Shields on certain counters together with coincidence techniques would enable alpha particles to be distinguished from gamma rays.

An alternate possibility is to measure the background of alpha particles and their energy spectrum. Inferences or estimates of the gamma ray background can be made from the alpha particle spectrum.

4.3.4 SURFACE AND SUBSURFACE PHYSICAL PROPERTIES

a. Surface and Subsurface Temperatures. The environmental temperature is indicative of the possible rates of biochemical reactions and the need for special adaptations to prevent biological fluids from freezing. At low temperatures life processes are inhibited or require considerable energy expenditure to maintain an internal temperature higher than the immediate external environment. Diurnal variations, if extreme, are important, also. Repetitive daily freezing and thawing cycles are detrimental to many organisms.

The measurement of water vapor pressure below the surface is a high priority environmental experiment for ABL[9] However, such a measurement does not constitute a direct measure of available water sources without a corresponding measurement of temperature. Only the water vapor in equilibrium with water of all forms is indicated. This subsurface water may be liquid or frozen and may contain dissolved salts of unknown concentration and identify. Or the water may be available only as water of hydration of some salt. The vapor pressure of water is lowered from that of pure water if it contains solutes. Thus, a simultaneous, local temperature measurement is needed to allow estimates of the state of binding of water which may be available to subsurface life.

Thermal mapping of the near surface will indicate possible warm microenvironments and their location. This information may be used to aid remote sample site location.

Temperatures of sample sites should be measured routinely before sampling as one piece of essential information characterizing the sample. A series of temperature measurements as a function of depth together with

corresponding humidity and soil gas composition will provide important information concerning subsurface ecological regimes.

Surface thermal mapping would be accomplished with a scanning, small angular aperture, infrared radiometer operating in the wavelength region from 8-13 microns or beyond. Surface and subsurface temperatures at selected sites would be measured with thermocouple probes. Surface skin temperatures can be monitored with a contact thermocouple. Subsurface temperatures are most easily measured by a spike or modified Proctor plasticity needle containing a thermocouple at its distal end.[12] The needle would be mechanically inserted into the surface.

b. Surface Material Electrical Conductivity. To gain further information as to the physical and chemical nature of surface materials, a measure of electrical conductivity may be useful. Moisture and salt content of soils may be estimated from this measurement and water vapor measurements.

To measure electrical conductivity, the voltage - current characteristics can be measured between two spaced electrodes which are brought in contact with the surface material. Another technique which may be used measures electrical permittivity by changes induced in a resonant tank circuit when brought into close proximity of the soil. Such sensors as these could be incorporated into a sonde which traverses a borehole drilled in the surface.

c. Density of Surface and Subsurface Materials. A knowledge of soil density would enable additional estimates of particle sizes, soil type, and composition. For example, it would be possible to distinguish a humus from an inorganic soil. Biological activity in soils often leads to increased porosity and breakdown of organic materials resulting in humus.

A technique for determining the gross soil density utilizes the back-scattering of gamma radiation from a source to a detector. The density measurement can also be made using probes inserted in the soil or a sonde lowered down a borehole.

The TEI instrument[12] designed for this purpose may be modified to reduce its size. However, two dimensions are critical, the distance between the gamma ray source material (Ir^{192}) and the counter and the elevation of the counter above the ground. In use the instrument directionally bombards the surface with gamma rays and the radiation received at the counter records the amount of scattering, which is directly related to the density of the target material.

d. Soil Mechanics. Additional information on soil structure can be obtained by performing simple mechanical tests on the surface. This information is also useful in correctly selecting sample collection tools or equipment. Bearing strength and shear strength would be measured. Soil porosity can also be measured by determining its resistance to a flow of gas directed through the soil. A typical soil mechanics package might include:

(1) A spring or hydraulically actuated flat plate

(2) A spring or hydraulically actuated cone penetrometer

(3) A spring or hydraulically actuated spear with a tungsten carbide tip and accelerometer

(4) For hard materials, an explosively actuated spear with a tungsten carbide tip and accelerometer

(5) A shear test vane

The spears or plasticity needles measure the resistance to penetration of a soil as a function of gradation due to poor sorting or layering, a degree of density per layer, and the frictional resistance existing between soil grains and the small-area bearing surface of the probe. These factors basically determine the compaction of the soil. The flat plate, cone penetrometer, and the shear vane should be located away from the footprint area to negate the effect of the weight of the ABL on the soil. In application, the plates will have varying diameters but will be forced into the soil with equal loads governed by the weight of the ABL. Attached to the mounting holding the bearing strength plates and separated from the smaller plate by 2-1/2 plate diameters, a shear test vane can be set up. The instrument consists of rigid vanes welded to a small diameter shaft. The vanes are forced into the soil, wholly or partially, and rotated 120 degrees. The torque applied becomes the measure of soil shear strength. Such a collection of devices would provide data for calculation of static bearing strength, shear strength, and penetrability at high and low velocities.

Although such a package would weigh only several pounds, a much less detailed set of measurements may suffice and would weigh less. For example, a pair of annular rings could be forced against the surface and the penetration or sinkage history measured. A vane inserted in the soil and twisted can be instrumented to determine soil shear strength. It may even be possible to instrument the soil sample collection equipment with appropriate sensors to obtain useful data of soil mechanical properties.

e. Soil Particle Size and Particle Density Distributions. A further meaningful characteristic of the subsurface bioenvironment is soil particle size and density distribution.[13] Such information would also augment a geological study of weathering of exposed surface materials and rocks. Particle sizes from sand grains to as small as micron diameter dust particles are of interest. Very rough indications of particle size distribution can result from sample grading and refining operations (dry sieving). A microscopic and petrographic analysis of soil particles is probably outside the control and data transmission capabilities of a 1975 Voyager mission. However, a polarizing microscope could provide useful geological, as well as biological, information.

f. Water Binding Capacity. An experiment in which water is metered to a known amount of minimally disturbed surface material until the sample does not retain more will provide data indicating soil type and its capacity to bind or hold free water. Such a measurement would elucidate the extent to which permafrost deposits can be formed by sifting of dust through clouds of vapor at the poles.[14]

g. Density of Objects. It would be useful to be able to quickly determine the density of macroscopic objects suspected of being largely organic in composition, since a simple nondestructive check on the gross composition would thereby be possible. A gas pycnometer has been suggested for this purpose.[13]

h. Acoustical Monitoring. A device such as a microphone and resonant chambers might be profitably employed to detect changes in ambient sound intensities and perhaps spectrum. Wind and impact sounds would be monitored. Noises produced by living forms also could be detected.

4.3.5 SURFACE AND SUBSURFACE CHEMICAL PROPERTIES

The chemistry of surface materials is perhaps the most important area of environment measurements for a mission to detect and characterize life. The chemical information is also highly interesting to other scientific disciplines.

a. Elemental Soil Analysis. The chemical environment of surface and subsurface life should be measured.[8,9] A broad elemental analysis of a soil sample is useful in that it can provide indication of unusual chemical composition which more specific analyses, say for specific inorganic ions, would miss. The elemental analysis also provides information about biologically interesting elements. The elements of principal interest are C, N, O, S, P, Mg, K, Ca, Fe, and Si.[8]

A good technique for measuring elemental composition in the low atomic number range is by alpha particle backscattering. The energy spectrum

of alpha particles scattered through a given angle is indicative of the elemental composition. Furthermore, the analysis method requires minimal sample preparation. Alpha-proton reactions also provide additional supporting information if appropriate proton sensors are included with the instrument.[17]

Light elements are detected by alpha-proton reactions and elements with an atomic number greater than 4(Be) by alpha scattering. Elemental resolution is based on atomic number groups; single elements from 4 to 17 (Cl) can be resolved, from 18(Ar) to 25(Fe) resolution is based on groups of 2 elements, and finally at the level of U(92) resolution groups include 10 elements. Both the elements predominant in biochemical structures and the more common rock forming mineral elements are among those most easily resolved and most prominently displayed.

The alpha scattering technique employs alpha particle sources and a set of small semiconductor detectors suitably arranged and oriented around the sources. A scattering angle of 160 degrees is typical. The sample is placed directly beneath the sources and detectors. A vacuum is necessary to prevent attenuation of alpha particles by air above the sample.

Semiconductor proton detectors protected with alpha particle absorbing shields can be used in conjunction with alpha detectors to measure the intensities and energies of protons produced by alpha-proton reactions in the sample. Additional information aiding identification is provided thereby. Carbon, oxygen, and heavy elements do not produce protons but B, N, F, Na, Mg, Al, and Si produce useable spectra. The utility of this additional technique is illustrated by the example of sodium detection. The alpha scattering spectrum of sodium may often be obscured by the presence of large quantities of silicon and magnesium. However, its proton spectrum is readily distinguished from that of silicon and magnesium.

b. Water Content. Water is a critical solvent for most biochemical reactions and is essential to life processes. The availability and type of water in Martian soil are therefore important measurements.

Measurement of water vapor partial pressure below the soil, perhaps using a sensitive gold film - aluminum oxide sensor,[10] is only a first step in detecting and estimating the availability of water. A more complete determination of the quantities and states of binding of water in a surface sample can be accomplished with a programmed volatilization of a minimally disturbed soil sample. Other volatile materials would also be evolved with the water and must be distinguished from water vapor. Gas chromatography of the volatilized vapors, differential thermal analysis, and thermal-gravimetric analysis are possible techniques for this purpose. This experiment may also logically precede an

experiment to detect organic matter in soil by pyrolysis gas chromatography. A soil sample would be subjected to programmed heating to remove residual water and other gases which are analyzed. Subsequently, the soil sample would be raised to temperatures high enough to induce pyrolysis of the less volatile organic components.

Subsurface moisture in the vapor phase can be sampled by means of a further modification of the Proctor plasticity needle[12] to include a micropermeable window near the inserted end of the needle. A slight vacuum will pull soil gases into the gas sampling line and port them past a water sensor or to the gas chromatograph.

c. Soil Gas Analysis. Biochemical activity in soils can result in a gaseous composition which differs from ambient atmospheric composition. The identity of evolved soil gases can provide evidence for certain biochemical processes. Specifically, the gases of particular interest include CH_4, CO_2, CO, O_2, O_3, H_2O, H_2S, H_2, NH_3, N_2, NO, NO_2, and SO_2. Soil gas composition should be measured as a function of depth of a probe (or modified Proctor plasticity needle) introduced for extraction of the gas.

d. Soil pH. The soil pH can be estimated indirectly by measuring the pH of an aqueous extract of a weighed soil sample with a known quantity of water. This information when combined with other measured properties of the soil will permit approximation to the actual hydrogen ion activity in the virgin soil.

e. Soluble Inorganic Ions. Further characterization of soil chemistry involves identification and quantitative determination of particular water soluble inorganic anions and cations that are known to play a role in terrestrial biology. Ions of interest include Na^+, Mg^{++}, Fe^{++}, Fe^{+++}, Co^{++}, Cu^{++}, Zn^{++}, Mn^{++}, $CO_3^=$, $PO_4^{\equiv}$, $SO_4^=$, NO^-_3, NO^-_2, $S^=$, and Cl^-.

Most of these ions can be determined by a combination of chemical processing (either a simple aqueous extraction of soil followed by evaporation to concentrate salts or chemical treatment designed to isolate certain classes of the ions, for example, precipitation of carbonates or sulfates) and α-scattering analysis. The heavier elements such as Co, Cu, 2n, Mn are best analyzed for using chemical processing and possibly X-ray fluorescence spectroscopy[16] or perhaps colorimetric techniques.

X-ray fluorescence may be excited in a sample with either electrons or X-rays. For the case of a mission to Mars, use of X-ray excitation would be preferred to avoid atmospheric absorption of electrons or to avoid employing a vacuum pump to remove the air between the sample and excitation source (an electron gun).

f. Organic Carbon in Soil. The presence of carbon in the form of organic compounds is particularly relevant to biology.[8,9] If no organic material is present, carbon based life certainly cannot be very populous. Simple detection of the presence of organic material is a valuable piece of information. Pyrolysis of a soil sample will cause degradation and volatilization of complex organic molecules which may be detected with a sensor sensitive to organic vapors. Sensors used in gas chromatography could also be adapted to this purpose.

A quantitative determination of organic and inorganic carbon and organic hydrogen in soil would be a more refined experiment producing more specific and detailed information. For example, a soil sample could be treated with sulfurous acid to decompose inorganic carbonates and eliminate their possible interference with the subsequent organic carbon determination. The carbon dioxide evolved as a result of the sulfurous acid treatment could be quantitatively measured or a total soil carbon determination could be performed in parallel on another portion of the same soil sample. By difference with the organic carbon determination, the inorganic carbon would be estimated. The actual procedure for carbon determination would utilize a dry or wet combustion technique. For example, the sulfurous acid could be evaporated at 25°C under reduced pressure and the dry residue subjected to oxidative combustion. Liberated water and carbon dioxide would be assayed with a gas treatment train and gas chromatograph or some other suitable detector.

g. Fractional Solubility of Surface Material. Useful data is obtained about a complex material such as a soil by determining the solubility classes to which the various soil constituents belong. A soil sample or portions of a sample rendered homogeneous by mechanical treatment would be extracted with a selection of solvents of different dielectric constant, polarity, etc. The amount of material dissolved would then be assayed after evaporation of the filtered extract by weighing. The residues perhaps could then be used in subsequent biochemical determinations or life detection experiments.

h. Fractional Volatility of Surface Material. A programmed volatilization of a soil sample may be identical to the volatilization technique described in 4.3.5b for detection of soil moisture. The resulting data would further characterize a sample. No additional equipment is required other than that used for pyrolysis gas chromatographic detection of amino acids except a capability for gradual heating of the sample.

4.3.6 VISUAL INFRARED IMAGING

Before extensive sample gathering operations are initiated, except for routine sampling at the immediate landing site, the surroundings and terrain should be surveyed. Visual inspection equipment is required

for this purpose. A broad spectral band would be used in the visible region possibly in conjunction with color filters. Panoramic pictures (360 degrees around the landing site) of the surface so that surface objects are in view extending from immediately below the ABL to a few degrees of inclination above the horizon are desirable. In addition, an infrared survey should be made using a scanning radiometer equipped with filter and sensors which respond to wavelengths in a selected water absorption band and in a broad wavelength region covering ambient thermal variations. The visual picture would be analyzed for signs of life such as vegetation, spoor, carcasses, and fossil remains. The infrared scans would locate gross thermal and moisture anomalies. The resolution of the infrared imaging need not be as high as for the visible pictures.

Both a vidicon camera and a facsimile camera are capable of producing pictures of high resolution. Both can record pictures sufficiently rapidly to stop rates of motion of interest. The data transmission capability of the ABL will be limited. Since pictures require more bits than any other experiment, the quality of imaging should be limited and adjusted as necessary for integration into the ABL system. An advantage of the facsimile camera over the vidicon is that the data production rate can be matched to the data processing or transmission rate. The camera scan rate can be adjusted for low or moderate bit rate transmission. The vidicon takes a picture essentially all at once, and this data must be stored and fed gradually to the transmitter. It is possible using the facsimile camera to spend a part of each day over a period of days to obtain a complete picture. The picture could be transmitted piece by piece rather than allowing the whole picture to occupy the available memory so that other experiments are penalized while the complete picture is being transmitted.

The resolution of the visible imaging system in the wide angle or panoramic scanning mode need not be great. The human eye has a resolution of about one minute of arc. Such resolution is far greater, perhaps by over an order of magnitude, than that needed for panoramic scans. Thus, a resolution between 1/6 and 1/2 of a degree would be adequate. In selected local areas near the landing site, limited fields of view could be investigated with higher resolution. If an interesting object is located by the panoramic scan, a close up inspection with a resolution equivalent to the human eye or better would be possible.

Stereo pairs are useful in locating the ranges of distant objects. Furthermore, they are an aid in interpreting pictures, especially in shadowed areas. Color separation is also very helpful. Three filters (blue, green and red) are recommended, especially when the wave of darkening is passing the ABL landing site. A grey scale of 16 shades of grey is adequate for surface pictures.

Basic measurements of the degree of slope of the surface from the location of the ABL to the horizon and measure of microrelief and surface roughness can be accomplished with a stereo scan. Textural details of the soil can be observed at a maximum resolution of the nonstereo near-field scan. The textural characteristics will include grain size, shape, sorting, and packing, and amount of visual porosity for larger scale particulate material ($\sim$ 0.1 inch). The presence of fossil material or organic modifications of the surface may be indicated. The existence of inorganic or organic stains, surface coatings and alternation products may be demonstrated by detailed study and terrestrial analogy.

Since only a limited number of pictures can be transmitted, careful selection of the time at which the pictures are taken is mandatory. A picture of the surroundings shortly after landing is required to aid selection of remote landing sites and as a preliminary life detection experiment. Also, the immediate vicinity of the ABL would be examined with higher resolution in limited areas. Eventually, each selected sampling site should be subjected to a high resolution examination. Pictures should be taken at intervals corresponding to the seasons, winter, spring, summer and fall. Several pictures are desired during the wave of darkening and whenever sudden changes in the meteorological conditions (pressure, temperature, and wind) are detected.

4.3.7 EVALUATION OF SUGGESTED EXPERIMENTS

Although all of the above described environmental experiments were selected because they have meaning in biological exploration of Mars, further relative evaluation and ranking is useful in selecting an experimental complement. Such an evaluation enables selection of the most essential measurements for the representative design point ABL mission.

The detailed evaluation is based upon the degree to which a particular experiment satisfies the following essential criteria:

(1) The experiment must be performed before meaningful biology experiments can be successfully performed. For example, the experiment might aid in selection of culturing conditions or media, processing procedures and operations, or in characterizing the sample in some essential manner. Thus, the environmental experiment may indicate the choice of some biological experimental procedure in cases where alternatives exist, or it may simplify or assure the proper interpretation of results from a biological experiment. Equally important, the environmental experiment may itself provide suggestive data indicating the possible existence, or the actual presence, of life.

Careful sample collection and wise choice of sampling sites can influence importantly the success or failure of some biological experiments. For example, some experiments devised to detect biochemicals require fair concentrations of the biochemical in the sample. By selecting a sample for a site judged likely to be opportune for accumulation of such an organic material, the chances of successful detection of the chemical are increased.

(2) The experiment must characterize the ecological conditions affecting Martian biota, or characterize conditions responsible for the extinction or preclusion of life. The experiment may detect or help locate fossils or residues resulting from previously living forms. This is an important secondary function of the ABL since, if existing life is not found, the next logical questions are related to reasons for its exclusion or disappearance, as discussed in the scientific objectives of Section 2. Thus, information on factors which could prevent life from developing on Mars or explain the extinction of possible previous life are derived from environmental measurements.

The experiments described in the previous section were evaluated on the basis of a number of factors essential to the above criteria. Each was asigned a numerical score based on its ability to satisfy these criteria. Appendix 4 of Volume VI describes this actual evaluation in detail. Using these scores the experiments were then ranked and the results are given in the next section.

4.4 TECHNICAL RESULTS AND CONCLUSIONS

Results of the evaluation of suggested environmental experiments are summarized in Table 4-I which gives, in the order of decreasing merit for a biological mission, the identifying numbers and short titles of the experiments and their scores from the analysis discussed in Appendix 4, Volume VI.

This relative ranking was used, together with engineering tradeoffs, to select a representative complement of environmental experiments for the ABL. As an initial point, the higher rated experiments down to a score of about 100 were considered for the design point ABL mission. As will be shown in Section 5, the cost of inclusion of some experiments of lower rank was so low that they have been added.

Some of the experiments with low scores can be accomplished without added instrumentation by using instruments required for biological and higher ranked environmental experiments. All that is required in many cases, is that the experiment be programmed and that the data and power capability be available. For example, the visual and infrared scans of the sky (scores 46 and 30, respectively) can be accomplished with equipment used for the visual scan of the terrain (score 248) and radiometers (scores 159 and 151). Thus, although these experiments are scored fairly low, they can be readily accomplished if deemed desirable.

4.5 RECOMMENDATIONS

The inclusion of environmental experiments with scores above 100 is highly recommended. Experiments with scores above 150 are almost mandatory for a comprehensive biological payload. Most of the suggested experiments with scores less than 100 are desirable and should be included if engineeringly feasible.

TABLE 4-I

RANKING OF ENVIRONMENTAL EXPERIMENTS

	Experiment	Score
4.3.5 c.	Soil Gas Analysis	290
4.3.6 a.	Visual Scan	248
4.3.5 e.	Soluble Inorganic Ions	224
4.3.5 a.	Elemental Analysis	216
4.3.4 g.	Density of Objects	206
4.3.5 g.	Fractional Solubility	205
4.3.5 h.	Fractional Volatility	203
4.3.5 f.	Organic Carbon	192
4.3.5 d.	Soil pH	176
4.3.5 b.	Water Content	172
4.3.1 f.	Windborne Materials	169
4.3.4 a.	Surface Temperature	167

TABLE 4-I (Continued)

	Experiment	Score
4.3.1 d.	Atmospheric Composition	166
4.3.6 b.	Radiometer Scan (Water)	159
4.3.6 c.	Radiometer Scan (Thermal)	151
4.3.4 c.	Density of Surface Material	150
4.3.4 b.	Electrical Conductivity	131
4.3.4 e.	Particle Sizes and Densities	130
4.3.4 d.	Soil Mechanics	126
4.3.2	Solar Radiation Experiments	112
4.3.1 e.	Atmospheric Humidity	103
4.3.1 b.	Wind	85
4.3.4 f.	Binding Capacity	79
4.3.1 c.	Air Temperature	75
4.3.1 a.	Atmospheric Pressure	71
4.3.4 h.	Acoustical Monitoring	66
4.3.1 g.	Visual Scan of Sky	46
4.3.1 i.	Cloud Composition	34
4.3.3	Ionizing Radiation Experiments	33
4.3.1 h.	Infrared Scan of Sky	30

4.6 REFERENCES

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7. Kaplan, L. D., G. Munch, and H. Spinrad, Astrophys. J., 139, 1-15, 1964.

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SECTION 5

SCIENTIFIC PAYLOAD DEFINITION

5.1 SELECTION OF EXPERIMENT COMPLEMENT

5.1.1 GENERAL

The definition of appropriate biological and environmental experiments for the ABL mission discussed in Sections 2, 3, and 4 covered the broadest possible range. This was appropriate since the intent of these studies was to consider all possible important experiments. While such studies were necessary and appropriate, the reason for selecting an experiment complement, as a part of this study, was to investigate the requirements imposed on a planetary exploration payload by the inclusion of experimental capability appropriate to and representative of ABL missions. Such payloads must be compatible with launch environments, state of the art in numerous technologies, and similar missions related considerations, as well as with the scientific considerations. The previously mentioned investigations produced a large list of possible experiments for selection. To proceed into the systems engineering aspects of the study, it was necessary to determine the combinations of experiments to be employed in a representative payload. While every effort was made to assure that the resulting experiment complement was scientifically sound, the more important consideration at this point became:

> Do the selected experiments result in an instrument complement which is representative and comprehehensive enough that instrumental and payload engineering problems encountered in its analysis will represent the majority of such problems to be found in any reasonable ABL.

The importance of this objective cannot be overemphasized. The final selection of the experimental complement for any ensuing ABL is the appropriate function of NASA, working in conjunction with the National Academy of Science and other established scientific bodies. However, if the essential engineering problems can be identified, even at this early date, these need not wait for the final experiment selection for their solution. To this end a specific experimental payload was selected and the resulting instrumentation, processing and support equipment defined. These selections will be discussed below. Particular note should be taken in Paragraph 5.3 of the extremely broad analytical capability exhibited by the instrument complement resulting from this selection. Although these instruments were defined by the experiments identified in the next paragraph, they are capable of performing a far more comprehensive complement of experiments. A brief discussion of this extensive alternative capability is given in Paragraph 5.4 of this volume.

5.1.2 CONSTRAINTS FOR EXPERIMENT SELECTION

At the direction of NASA, Aeronutronic was instructed to employ the following guide lines for the experiment complement selection and resulting preliminary design feasibility study.

(1)	Mission Time:	1975
(2)	Payload Size:	500-1000 pounds
(3)	Mission Philosophy:	The mission to be a comprehensive biological, and related environmental mission, probably following orbital, and possibly simple entry or landing, missions in 1969, 1971, and 1973.

In addition it was assumed that any previous basic surface environmental measurements made in earlier missions would be repeated on the ABL missions in order to serve as a statistical refinement of the earlier data. Such measurements would also serve to record any variation that might exist due to differences in season or surface location between the two missions. As previously pointed out, such measurements also need to be made simultaneously with the biological experiments in order to provide correlative interpretive information.

5.1.3 EXPERIMENT COMPLEMENT

Table 5-I lists the 35 experiments selected for this representative payload complement. In addition to the evaluations performed and reported in Sections 3 and 4, subsequent inputs effecting the selection given in Table 5-I included recommendations of the Committee on Landers of the ad hoc Biosciences Group chaired by Dr. Wolf Vishniac[1], recommendations.

TABLE 5-I

SELECTED REPRESENTATIVE DESIGN POINT EXPERIMENT COMPLEMENT
(AND COMPARISON WITH OTHER SUGGESTED EXPERIMENTS)

ABL Design Point Experiments No., and Abbreviated Title	Equivalent Experiments								
	(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Aeronutronic Evaluations			ad hoc Work'g Group		JPL Min Bio Payload Study			Bio Sub-Comm-NAS
	Bio Experiments		Environ Exper	Payload I	Payload II	Payload I	Payload III	Payload IV	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vi)	(vi)	(vii)
1. Atmos Temp, Press, and Wind			4.3.4a 4.3.1a, b, c	3 6	3 6	X (except wind)	X (except wind)	X (except wind)	2
2. Atmospheric Humidity			4.3.1e	1	1	X	X	X	3
3. Wind Transported Particles			4.3.1f						1 (viii)
4. Acoustical Monitor			4.3.4h						4 (UV)
5. UV & Visible Insulation Flux			4.3.2	4 (UV)	4 (UV)				
6. Ionizing Radiation Background			4.3.3						
7. Atmospheric Composition			4.3.1d	2	2 20	X	X	X	1
8. Soil Temperature and Water Content			4.3.5b	5 6	5 6		X	X	5
9. Soil Electrical Conductivity			4.3.4b		13				
10. Soil Density by γ-Ray Sonde			4.3.4c						
11. Soil Mechanics			4.3.4c 4.3.4d						6 (viii)
12. Soil Sample Encapsulation									
13. Elemental Soil Analysis			4.3.5a		23 (α-scattering) 24		X	X	6 9
14. Soil Gas Analysis			4.3.5c	7 10	18, 7 10, 20				7
15. Soluble Inorganic Ions & pH			4.3.5e 4.3.5d		13 (pH)			X	22
16. Organic Material in Soil	IV	IV	4.3.5f	9	9, 15		X	X	13
17. Soil Gas Exchange	I-23	I-A-2			20			X	8
18. Amino Acid Analysis	IV-1	IV-A-4							
					14				19

19. Amino Acid Detection & Optical Activity	IV-1 and (Opt Act)	IV-A-3 and (Opt Act)							
20. Detection of Porphyrins	IV-8a,b	I-A							11
21. Detection of Flavins	IV-12	IV-B-2							
22. Detection of Non-Saponifiable Lipids	IV-10	IV-A-1							
23. Detection of Saponifiable Lipids	IV-9	IV-A-2							
24. Macromolecules by Visible Absorption	II-B-3	II-B							12
25. Macromolecules by UV Absorption	II-B-1	II-A							16
26. Water Soluble Macromol by Optical Activity	II-B-2	II-B-2							18
27. Water Soluble Macromol by Pyrolysis G C	II-B-1 and IV-1	II-A and IV-A-4							17
28. Functional Group Analysis	(See Par, Vol. II)	5.4						X	21
29. Light and Dark $C^{14}O_2$ Fixation vs Temperature	I-7-8	I-A-1			21 (Photo Syn not Necessary $C^{14}O_2$)				26
30. CO_2 Evol by Normal Metabolism	I-23	I-A-2						X	27
31. $C^{14}O_2$ Evol from Labeled Substrates	I-6	I-A-3							
32. $C^{14}O_2$ Uptake from Labeled Substrates & Evolution of C^{14}	I-6, 7, 8	I-A-4							
33. Culture Evaluation & Growth Detection	III 4, 6 III-12	III-A III-B							
34. Optical Motion Detection									3 (viii)
35. Visible and IR Macroimaging	VI-2	VI-A	4.3.6a, b, c 4.3.1h, i, g						28 29

(i) Nos. refer to those used in Table 3-II and in rating table of Appendix 3, Vol VI

(ii) Nos. refer to those used in Table 3-III and the procedural descriptions in Appendix 3, Vol VI.

(iii) Nos. refer to those used in Table 4-I and in Appendix 4.

(iv), (v) Nos. refer to those used in Tables I and II in Appendix 8.2

(vi) From Appendix 8.3, Table II

(vii) From Appendix 8.4, Table I

(viii) From Appendix 8.4, Table II

and suggestions provided by members of the Bioscience Subcommittee of the National Academy of Science at the April 1965 meeting held at Pennsylvania State University[2], and by the results of a study of a Minimum Biological Payload performed by Dr. George Hobby's organization at JPL [3] and reported at the previously mentioned ad hoc Bioscience Group meeting held in March 1965, at Newport Beach, California.[4] The columns on Table 5.I have been prepared to indicate how the listed experiments relate to those which have been suggested or recommended by these, and other sources working in exobiology.* Column (1) lists the equivalent experiment from Aeronutronic's rating of biological experiments in Appendix 3, Column (2) the similar rating by Aeronutronic of environmental experiments in Appendix 4. Columns (3) and (4) indicate experiments recommended by Dr. Vishniac's ad hoc group which are described in Appendix 8.2. Columns (5) and (6) and (7) are representative experiment complements taken from Dr. Hobby's report.[3] The results of which are summarized in Appendix 8.3 of this report. Column (8) reflects suggested experiments from the April 1965 meeting of the Bioscience Subcommittee and which are described in more detail in Appendix 8.4.

A review of the experiments in Table 5.I will show that those numbered 1 through 13 are measurements of the basic environmental factors most important in defining the bioenvironment and for interpreting the results of the biological experiments. The experiment listed as number 12 is not actually an experiment in itself, inasmuch as no specific result is expected from the ABL due to its inclusion. It is felt, however, to be an extremely important "operation" which should be included in the ABL (and on any earlier landing missions as well) to provide an uncontaminated soil sample to serve as a bench mark from which to measure subsequent experimental results.

A large class of experiments, numbers 14 through 28, are concerned with the detection and characterization of materials having important biological implications but not requiring growth (with the possible exception of number 17). Such experiments are important in defining both the bioenvironment and the basis for any existing organic chemistry. In addition, if viable life forms do not currently exist, these experiments will give us our only clues to possible biological precursors or fossil material.

A third class of experiments, numbers 29 through 32, are growth experiments, specifically intended to detect metabolic processes in any existing organisms, and the effect of light on these processes. A wide range of growth media would be carried in order to maximize the possibility of obtaining growth. This group of experiments are the only ones absolutely dependent on finding life essentially as we know it.

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*A rigorous correspondence between the experiments listed in various columns is not intended. Details of suggested experimental procedure may vary between sources. Correspondence does imply, however, a common interest in the experimental objectives and, in the majority of cases, also, agreement in general procedural approaches.

An important experiment, number 33, has been added to this complement for the two specific purposes of:

(1) Testing various growth media in an attempt to determine optimum compositions, and

(2) To employ the successful media to grow-up a quantity of organisms for additional analysis. The intent is to provide biological material in quantity on which many of previous basic experiments can be repeated with a higher probability of producing meaningful and unambiguous results.

The remaining two experiments, numbers 34 and 35, are concerned with optical and IR viewing of the surface. These experiments give both environmental and biological information and are the only experiments specifically capable of detecting intact macro-life forms, except for the acoustical monitor. In addition, the versatility of the optical system to detect change or motion, color, IR, and to provide stereoimages, make its inclusion important for a comprehensive mission, even though resulting data output places a severe load on the communication link.

Descriptions of the experimental procedures identified for performing these experiments are presented in the next section. The resulting instrument complement required to perform the experimental procedures as defined are identified and described in Paragraph 5.3.

5.1.4 REFERENCES

1. "Report of the Committee on Martian Landers," Subcommittee of the ad hoc Bioscience Working Group meeting held in Newport Beach, California, 22-26 March 1965 (See Appendix 8.2, Volume VI of this report).

2. Recommendations on ABL-class experiments by the Biosciences Subcommittee, NAS, transmitted informally to Aeronutronic through the Bioscience Programs Division, NASA Headquarters (See Appendix 8.4, Volume VI of this report).

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4. See Appendix 8.1, Volume VI of this report.

5.2 DEFINITION OF SELECTED EXPERIMENTAL PROCEDURES

5.2.1 INTRODUCTION

This section defines in detail the experimental complement identified in Paragraph 5.1 and the associated procedures. The definition of these experimental procedures is necessary in order to identify functions which must be performed and to determine the associated equipment for the ABL preliminary design.

Detailed descriptions of each experiment, step-by-step procedure outlines, and step-by-step time phased block diagrams are given in Appendix 5 of Volume VI. A summary description of each experiment is given in Paragraph 5.2.2. In referring to the time-phased diagrams in Appendix 5, the numbers in the circles correspond to the step number in the procedure outlines. A coding has been employed to indicate where commands are required and the type, as well as the step, at which data is produced. The predominant type of command used originates in the ABL computer. Earth commands will be used primarily to originate an experimental sequence or to modify the stored experimental program. Some experimental procedures require control feedback and arrive at decision points that must be made to continue the experiment. The implications of these features of command and control on the automation of an experimental sequence are covered more fully in Section 4, of Volume III.

5.2.2 SELECTED EXPERIMENTAL PROCEDURES

The following experimental descriptions are identified by the same number and presented in the same sequence as listed in Table 5-I of Paragraph 5.1.3.

Experiment 1: Atmospheric Pressure, Temperature, and Wind. This experiment is designed to measure the static pressure of the atmosphere, the dynamic pressure due to wind, the direction of the wind and the ambient atmospheric temperature. The experimental sequence while data is being taken requires 12 minutes. This experiment is monitored on a continuous basis and data is recorded either on demand or whenever a predetermined threshold level is exceeded.

Static and dynamic pressure will be measured with a pitot tube connected to a sensitive aneroid bellows. The unit will have the capability of traversing 360 degrees so that peak dynamic pressure can be determined. The pitot head is servo driven to point in the direction controlled by the differential output of a pair of hot wire anemometers. The hot wire anemometers are also used to provide the necessary sensitivity at the low wind velocities. The ambient air temperature is measured by means of a thermistor or thermocouple referenced to a resistance heated mass controlled by a bimetallic switch.

Experiment 2: Determination of Atmospheric Humidity. This experiment is designed to measure the water vapor content of the atmosphere. The experimental sequence to acquire data is estimated at 3 minutes and is recorded on demand. A gold film/aluminum oxide element is used to determine humidity by measuring the change in resistance caused by water absorbed in the aluminum oxide. This sensor is based on a unit developed by Parametrics, Waltham, Massachusetts, under JPL Contract 950684, 31 December 1964.

Experiment 3: Wind Transported Particulate Matter. The purpose of this experiment is to detect particulate matter carried in the atmosphere and to obtain an estimate of the amount and size of particles carried by the wind. Counts of impingement by atmospheric particles on a resonator with a microphone pickup will detect the gross transport of relatively large particles. For finer particles, and to determine concentration, miniaturized particle collection will be used. The experiment is continuously monitored to detect a predetermined threshold level which may be used to initiate the sequence to make quantitative determinations. This experiment also serves as an engineering control sensor to detect hazardous operating conditions for the laboratory. A complete quantitative analysis will require approximately 50 minutes.

Experiment 4: Acoustical Monitor. This experiment is intended to detect surface noises such as might be produced by the wind in large plants, by animals, by atmospheric disturbances, or by the laboratory itself. A sensitive omnidirectional microphone is used as a sensor. It is not envisioned that the output will be a direct analog but rather an analysis of the frequency spectrum and intensity levels. This experiment is also continuously monitored and data is recorded when a predetermined threshold level is exceeded. The total duration of the experiment is dependent on the event and is estimated to be 5 minutes or less in duration for any specific event.

Experiment 5: Ultraviolet and Visible Insolation. This experiment measures the total solar flux incident at the surface of Mars. A simple integrating spectrophotometer capable of measuring the incident flux over fixed bandwidths is used. An objective lens with a field of view of approximately 2π steradians is used to give an integrated value of direct and scattered flux including the sun. The experimental cycle is initiated by command and requires approximately 5 minutes to perform the operational sequence.

Experiment 6: β and γ Radiation Background. This experiment is designed to obtain information on the β and γ radiation at the surface and to provide correlative back-up data needed to evaluate those experiments using radiation counting devices as sensors. Selected background radiation level at the surface of Mars is determined. Count rate is measured using proportional counters with a 2π steradian field of view. Pulse height discrimination is incorporated. This experiment is command initiated and requires approximately 22 minutes to complete an operational cycle.

Experiment 7: Determination of Atmospheric Constituents. The purpose of this experiment is to detect and determine the concentration of H_2O, O_2 N_2, CO_2, Ar, CO, NO, NO_2, and O_3 in the atmosphere. A gas chromatograph and a mass spectrometer detector will be employed. The experiment is command initiated and requires approximately 11 minutes to perform.

Experiment 8: Soil Temperature and Water Content as a Function of Depth. This experiment is designed to determine the temperature of the soil from the surface to a depth of 100 cm at 5 cm intervals and the water content of the soil at these same depth intervals. A soil probe is injected into the soil to a depth of 100 cm or as deep as mechanically possible. Thermocouples or resistance wire thermometers and gold film/aluminum oxide detectors are integrally incorporated in the probe at 5 cm intervals. Heating elements are incorporated to free any frozen water as vapor after initial temperature profiles and water vapor content have been determined. This experiment is command initiated and requires approximately 30 minutes per operational cycle.

Experiment 9: Soil Electrical Conductivity. This experiment is designed to determine the electrical conductivity as a function of depth in the Martian soil. This data is used as back-up to the other environmental and life detection experiments, giving an indication of soil moisture content and gross composition. Instrumentation on a core hole traversing sonde is used. Two types of instrumentation are possible. A direct measure will be made of electrical potential between two points in contact with the soil. This is simple to incorporate on the probe bow spring and will be used as a cross reference to the second method using a resonant tank circuit. Changes in the Q of the circuit are determined when the inductance is placed near the soil. This experiment is command initiated and requires approximately 90 minutes to complete. It should be noted that the experimental cycle is concurrent and identical with that of Experiment 10.

Experiment 10: Soil Density By γ-Ray Sonde. This experiment is designed to provide a measurement of soil density as a function of depth, essentially using a traversing sonde carrying instrumentation in a core hole from which a core drill sample is taken. In deep loose sand where no core hole can be made, the sonde will be capable of being driven into the soil without a hole. Supplemental measurements of soil temperature and humidity are made. A core hole sonde similar in design to that of Texaco Experiment, Inc., but with less instrumentation can be used. Soil density is determined using a gamma source and a Geiger Mueller counter to detect scattered radiation. Subsurface temperature is determined from an external resistance thermometer mounted on the bow spring and by means of a modified Michelson interferometer. Water vapor or humidity will be detected using the aluminum oxide/gold film water vapor detector.

Experiment 11: Soil Mechanics Determination. This experiment provides the information necessary to reliably select and use the proper sample collection equipment and provides environmental background to support the results of the life detection experiments. It will provide soil strength data in bearing and shear, porosity or permeability data, and some estimates of soil particle size distribution. This experiment is automatically initiated at the beginning of each soil sampling attempt. The actual soil mechanics evaluation is made in the first 30 minutes of a 60-minute sampling cycle. The estimate of soil particle size distribution is made concurrently with the soil grading and refining process.

Experiment 12: Soil Sample Encapsulation and Preservation. This is actually a processing requirement rather than an experiment. The purpose is to encapsulate and preserve for future analysis samples of unprocessed soil. A kilogram of soil will be taken at each sample site and will be preserved in a hermetically sealed container and identified by sample site location, date of collection, and existing environment, i.e., soil temperature, time of day, atmospheric temperature, atmospheric pressure, atmospheric humidity, and wind velocity. This experiment is initiated and executed concurrently with Experiment 11.

Experiment 13: Elemental Soil Analysis. This experiment is designed to determine the elemental composition of the soil as completely as possible without chemical processing. The elements of principal interest are C, N, S, P, Mg, Na, K, Ca, Fe, and Si. Samples taken by either the core drill or the regular soil sampler will be analyzed. An α-scattering analyzer will be employed using an α-source and solid state semiconductor detectors. This experiment is command initiated and requires 24 hours to complete.

Experiment 14: Soil Gas Analysis. This experiment is designed to determine the composition of soil gases extracted as a function of depth by the probe in Experiment 8. Specifically, the gases of interest are CH_4, NH_3, H_2O, CO_2, CO, H_2S, O_2, O_3, NO, NO_2, H_2, N_2, and SO_2. The sample is analyzed with a gas chromatograph and a mass spectrometer. The experimental cycle is automatically initiated when the soil probe in Experiment 8 is implanted and requires 40 minutes to complete.

Experiment 15: Determination of Soluble Inorganic Ions and pH. An aqueous extraction of the soil will be performed from which a determination of pH and presence of inorganic ions can be made. Ions of interest are: $CO_3^{\equiv}$, $PO_4^{\equiv}$, H^+, $SO_4^{=}$, NO_3^-, $S^=$, OH^-, CL^-, Na^+, Mg^{++}, Fe^{++}, Fe^{+++}, K^+, NH_4^+, Ca^{++}, Co^{++}, Cu^{++}, Zn^{++}, and Mn^{++}. This experiment involves chemical processing utilizing filtration, aqueous extraction and extract evaporation on a plate for α-scattering analysis. pH determinations will be made in the course of performing the chemical processing. This experiment is command initiated and requires approximately 28 hours per experimental cycle.

Experiment 16: Detection of Organic Material in Soil. This experiment is designed to detect the presence of organic material in a soil sample. The soil sample is subjected to a programmed heating to remove residual H_2O and gases, and is then followed by pyrolysis of the solid material. Complex organic materials are detected in the pyrolysis products. The evaporation and pyrolysis products are analyzed by first passing them through an argon β-ionization detector and then condensing the products on a glass plate for fluorimetric analysis. This experiment is command initiated and requires approximately 2.5 hours to complete.

Experiment 17: Soil Gas Exchange. This experiment evaluates the composition of gases evolved from a soil sample in situ for both an undisturbed sample and after the addition of labeled substrates. Gases of interest are H_2O, CO_2, O_2, CO, CH_4, H_2, NH_3, H_2S, SO_2, NO, NO_2, N_2 and the labeled gases $C^{14}O_2$, $C^{14}O$, $C^{14}H_4$, $S^{35}O_2$ and H_2S^{35}. A gas chromatograph and mass spectrometer are used to analyze the soil gases in addition to a β-ionization counter. This experiment is command initiated and requires 50.5 hours to complete an operational cycle.

Experiment 18: Amino Acid Analysis. This experiment is designed to detect amino acids using a programmed heating followed by pyrolysis of a graded soil sample. The pyrolysis products are analyzed using a gas chromatograph. The experimental cycle is command initiated and requires approximately 140 minutes to complete.

Experiment 19: Detection of Amino Acids and Optical Activity. This experiment differs from Experiment 18 in that chemical processing is performed involving extraction, filtration, and volatile derivative preparation. The basis of the experiment is that derivatives with two asymmetrical carbons have different stereochemistries and can be separated in the gas chromatograph column. This experimental cycle is command initiated and requires approximately 9 hours to complete.

Experiment 20: Detection of Porphyrins. The purpose of this experiment is to detect porphyrins by chemically extracting a soil sample. The solution is filtered and subjected to a fluorimetric analysis using an excitation source at the 405 mμ Hg line. This experimental cycle is command initiated and requires 2.5 hours to complete.

Experiment 21: Detection of Flavins. This experiment is designed to detect flavins by a spectrofluorimetric analysis. Chemical processing is required capable of performing a solvent extraction, programmed heating, and a liquid/liquid phase separation. The analysis is performed with a fluorimeter with the excitation source at 445 mμ and capability of scanning from 500 mμ to 600 mμ. This experimental cycle is command initiated and requires 6.3 hours to complete.

Experiment 22: Detection of Nonsaponifiable Lipids. This experiment is designed to detect nonsaponifiable lipids by means of a programmed volatilization of an organic soil extract and gas chromatograph analysis. Chemical processing capable of performing a solvent extraction, filtration, programmed heating and evaporation, and liquid/liquid phase separation is required. The analysis is performed using a gas chromatograph and mass spectrometer. The experimental cycle is command initiated and requires 7.3 hours to complete.

Experiment 23: Detection of Saponifiable Lipids. This experiment is to detect the saponifiable lipids by means of a programmed volatilization of the organic solution obtained in the liquid/liquid phase separation of Experiment 22. Chemical processing is employed capable of performing a solvent extraction, filtration, and a liquid/liquid phase separation. Analysis is performed by means of a gas chromatograph and mass spectrometer on substances extracted by organic solvents from the neutralized aqueous solution. The experimental cycle is command initiated and requires 9.1 hours to complete.

Experiment 24: Detection of Macromolecules by Absorption in the Visible Spectrum. This experiment is designed to detect macromolecules such as proteins and nucleic acid by measuring changes in the absorbence of an extract or a dye-extract solution in the visible spectrum. Chemical processing is required capable of performing a solvent extraction of a soil sample, a filtration, a dialysis, and preparation of a dye-extract solution. The analysis is performed using an optical-null spectrophotometer operating in the visible spectrum from 400 mμ to 700 mμ. The experimental cycle is command initiated and requires 4 hours to complete.

Experiment 25: Detection of Macromolecules by Absorption in the Ultraviolet Spectrum. This experiment is designed to detect macromolecules such as proteins and nucleic acid by means of absorbence of an extract solution in the ultraviolet region of the spectrum. Chemical processing is required capable of performing a solvent extraction, a filtration, and dialysis of the solution. The analysis is performed using an optical null spectrophotometer operating in the ultraviolet spectrum from 240 mμ to 350 mμ. The experimental cycle is command initiated and requires 3 hours to complete.

Experiment 26: Optical Activity of Water Soluble Macromolecules. This experiment is designed to detect macromolecules soluble in water by means of optical rotation. Optical rotation will be measured before and after dialysis of the solution. Chemical processing is required capable of performing a solvent extraction, filtration, and dialysis of the solution. The analysis is performed by means of a polarimeter operating in the UV spectrum at 270-290 mμ. The experimental cycle is command initiated and requires approximately 4 hours to complete.

Experiment 27: Detection of Water Soluble Macromolecules by Pyrolysis Gas Chromatography. This experiment is designed to detect water soluble macromolecules. Chemical processing is required capable of performing a solvent extraction, filtration, dialysis, and a programmed heating with pyrolysis. The analysis is performed with a gas chromatograph and a mass spectrometer. The experimental cycle is command initiated and requires approximately 3 hours to complete.

Experiment 28: Functional Group Analysis. This experiment is designed to identify and categorize the functional groups such as CH, C = C, NH_2, OH, C = O and COOH using infrared spectrophotometry. Chemical processing is required capable of performing extraction, and filtration. The analysis is performed with an infrared spectrometer operating from 2 to 14μ with a resolution of 0.1μ. The experimental cycle is command initiated and requires 4.5 hours to complete.

Experiment 29: Light Stimulated $C^{14}O_2$ Fixation and Dark $C^{14}O_2$ Fixation as a Function of Temperature. This experiment is designed to determine the amount of CO_2 fixed in an incubated soil sample. The samples are incubated at two different termperatures in light and dark with a tagged ($C^{14}O_2$) carbon dioxide in the chamber atmosphere. After incubation the soil is pyrolized to determine the amount of $C^{14}O_2$ fixed by counting the tagged carbon released. The experimental cycle is command initiated and requires 106 hours to complete.

Experiment 30: Evolution of CO_2 by Normal Metabolism. This experiment is designed to detect the evolution of CO_2 during normal metabolism. The soil is placed in culture chambers, and the atmosphere is purged of CO_2 and maintained as a N_2 atmosphere with a low O_2 content. The soil is incubated at two temperatures for a given time and the increase in CO_2 content of the chamber atmosphere is determined by a CO_2 detector such as $Ba(OH)_2$ solution. The increase in CO_2 is compared to that obtained in a sterile control specimen for each incubation temperature. The experimental cycle is command initiated and requires 158 hours to complete.

Experiment 31: $C^{14}O_2$ Evolution From Labeled Substrate. This experiment measures the amount of $C^{14}O_2$ evolved from an incubated soil sample to which a labeled substrate has been added. The labeled substrates are C^{14} formate and glucose-U-C^{14}. Two samples are heated to 120°C for 15 minutes after which one sterile and one control sample are equilibrated at 0-1°C and the other two at 30°C. The labeled substrate purged of $C^{14}O_2$ is added after incubation temperatures have reached equilibrium. Incubation proceeds for a given time and the rates of evolution of $C^{14}O_2$ are compared by measuring β activity. The experimental cycle is command initiated and requires 51 hours to complete.

Experiment 32: $C^{14}O_2$ Uptake in Light and Dark and Subsequent Evolution by Metabolism. This equipment is designed to compare the amount $C^{14}O_2$ fixed in light and dark with the amount of $C^{14}O_2$ re-evolved by metabolism. The samples consist of soil samples incubated in light and dark, and a sterile control sample. The samples are incubated at 25°C for a given time period in an atmosphere containing $C^{14}O_2$. After exposure to $C^{14}O_2$ atmosphere, the chambers are purged of $C^{14}O_2$ and one set each of light, dark and sterile samples are monitored to determine rate of re-evolution of $C^{14}O_2$. The other set of samples are combusted with oxygen and the amount of $C^{14}O_2$ fixed is determined. The analysis is performed by measuring β activity in the evolved gases. The experimental cycle is command initiated and requires 90 hours to complete.

Experiment 33: Culture Evaluation and Growth Detection. This experiment is designed to investigate various types and concentrations of culture media using both Earth formulated media and media prepared from Martian soil extracts. Each culture plate will be prepared so that it incorporates a nutrient gradient to identify the optimum concentration. The procedure will be to inoculate a series of culture media preparations from a common soil sample. These will be monitored to detect growth by increases in turbidity or optical density and pH changes. Localized changes will be determined by optical density surveys. If growth occurs, transfer plates will be made on successive culture plates for those culture media on which growth or changes have occurred most prominently. As many transfer cultures will be made as possible; up to a limit of 4. After growth has been established and the optimum media determined, life detection experiments listed below will be repeated to detect increases in biological material.

Experiment No. 17	Soil Gas Exchange
Experiment No. 20	Detection of Porphyrins
Experiment No. 21	Detection of Flavins
Experiment No. 22	Detection of Nonsaponifiable Lipids
Experiment No. 23	Detection of Saponifiable Lipids
Experiment No. 24	Detection of Macromolecules by Absorption in the Visible Spectrum.

This experimental cycle is command initiated and will require logic decision points -- probably Earth based. The total operational cycle time is indeterminate but requires a minimum of 78 hours to complete not including the repetition of experiments to detect increases in biological material.

Experiment 34: Motion Detector. This experiment is designed to detect motion if it should occur, such as plant movement in the wind, movement of animal life, and shadow or cloud movement. This motion detector consists of an optical system focusing an image on a photosensitive matrix. Variations in output from the detector matrix can be interpreted as motion. A 360^{o} x 60^{o} lateral field of view is desired. Coordination of output data from Experiments 4 and 35 is required to detect and identify possible macroscopic life forms. This experiment is continuously monitored and is activated when a predetermined threshold level is exceeded.

Experiment 35: Macroimaging and Infrared Scan. This experiment is designed to observe the morphological features of the surrounding terrain in the visible spectrum and to a lesser degree in the infrared spectrum. These scans are intended to detect macroscopic life forms, if they exist, and to detect thermal anomalies. From the low resolution scan results, a higher resolution scan of potentially desirable samples sites will be made. A facsimile scanning device may be used to obtain the visual picture and to map the thermal features of the terrain. The infrared scan is made simultaneously with the visible, as well as at the Martian midnight, maintaining coordination between scan points with the visible scan. The experiment cycle is command initiated and requires 24 hours to complete. The actual scanning time may vary from a few minutes up to 8 hours.

5.3 DEFINITION OF RESULTING INSTRUMENT COMPLEMENT

5.3.1 INSTRUMENT REQUIREMENTS

The experiments defined in Paragraphs 5.1 and 5.2 require 27 different types of analytical equipment and detectors to generate the data output for the 35 experiments. Table 5-II is a matrix which identifies the equipment associated with each experiment. In some cases, such as the core hole sonde and the atmospheric parameters sensor, a piece of apparatus housing a variety of sensors is implied. More detailed discussion of each of the analytical instruments in Paragraph 5.3.2 will identify these sensors and their functions. It should be pointed out here that these instruments are only those required to collect the experiment output data and do not include the sensors required to perform the processing and engineering functions of the laboratory. A possible exception is the weight scale which was included since it is needed to verify the initial sample involved. On this basis it does represent final output data.

Referring again to Table 5-II, it is seen that the predominating analytical tools for the primary life detection experiments involve radiation counters, optical instruments, gas chromatography, and mass spectroscopy. Of these, the gas chromatographs generally appear to be specialized for the particular type of experimental analysis desired. This is the result of having to choose a column packing which is appropriate to the type of determination being made. This does not imply that useful results cannot be achieved with a nonoptimum column packing in many cases. These instruments also are essentially the only ones which can be expected to change their characteristics as a function of usage. The problem unique to these instruments is that the column packing is susceptible to such deteriorating effects as chemical reaction with the sample, polymerization, bleeding of the stationary liquid phase, and progressive blocking of the column with heavy residual components of the sample. The implication inherent in any form of quantitative analytical instrument is that periodic calibration is required to establish a known base line and to detect changes in response characteristics. It is therefore assumed that each instrument will have associated with it some form of calibration standard. Wherever possible, a solid state reusable standard will be used. In some cases, specifically the mass spectrometer and gas chromatographs, a chemical standard will be required.

5.3.2 INSTRUMENT CHARACTERISTICS

In this paragraph the general configuration of each instrument and its operating characteristics are defined. The objective of this analysis was the establishment of feasibility, and the estimation of realistic configurations from which weight, volumetric envelopes, and power requirements could be estimated. It was beyond the scope of this study to perform a detailed

TABLE 5-II

EXPERIMENT/INSTRUMENT MATRIX

Experiment Number	Experimental Priority Code P_P - Most Primary P - Primary S - Secondary	Relative Priority	Thermometer	Atm
1.	Atmospheric Pressure, Temperature, and Wind	P	■	■
2.	Determination of Atmospheric Humidity	P		
3.	Wind Transported Particulate Matter	S		
4.	Acoustical Monitor	S		
5.	Ultraviolet and Visible Insolation	S		
6.	β and γ Radiation Background	S		
7.	Determination of Atmospheric Constituents	P	■	
8.	Soil Temperature and Water Content as a Function of Depth	P	■	
9.	Soil Electrical Conductivity	S		
10.	Soil Density by γ-Ray Sonde	S		
11.	Soil Mechanics Determination	S		
12.	Soil Sample Encapsulation and Preservation	P_P		
13.	Elemental Soil Analysis	S		
14.	Soil Gas Analysis	P		
15.	Determination of Soluble Inorganic Ions and pH	P		
16.	Detection of Organic Material in Soil	P		
17.	Soil Gas Exchange	P	■	
18.	Amino Acid Analyses	P	■	
19.	Detection of Amino Acids and Optical Activity	P	■	
20.	Detection of Porphyrins	P	■	
21.	Detection of Flavins	P	■	
22.	Detection of Nonsaponifiable Lipids	P	■	
23.	Detection of Saponifiable Lipids	P	■	
24.	Detection of Macromolecules by Absorption in the Visible Spectrum	S	■	
25.	Detection of Macromolecules by Absorption in the Ultraviolet Spectrum	S		
26.	Optical Activity of Water Soluble Macromolecules	P		
27.	Detection of Water Soluble Macromolecules by Pyrolysis Gas Chromatography	S	■	
28.	Functional Group Analysis	S		
29.	Light Stimulated C^1+O_2 Fixation and Dark C^1+O_2 Fixation as a Function of Temperature	P	■	
30.	Evolution of CO_2 by Normal Metabolism	P	■	
31.	C^1+O_2 Evolution from Labeled Substrate	P	■	
32.	C^1+O_2 Uptake in Light-Dark Subsequent Evolution by Metabolism	P	■	
33.	Culture Evaluation and Growth Detection	P	■	
34.	Motion Detector	S		
35.	Microimaging and Infrared Scan	P_P		

pheric Parameters Sensor
Gold Film/Al_2O_3 H_2O Vapor Detector
Microphone With Resonator
Omnidirectional Microphone
2π β and γ-Ray Counter
Core Hole Sonde
Soil Mechanics Apparatus
Optical Motion Detector
Optical Density Comparator
Macroimaging System
Infrared Radiometer
Solar Insolation Radiometer
pH Meter
Ba(OH)2 Conductivity Cell
β-Ionization Counter
α-Scattering Counter
Gas Chromatograph Analyzer
Gas Chromatograph #1
Gas Chromatograph #2
Gas Chromatograph #3
Gas Chromatograph #4
Gas Chromatograph #5
U.V. and Visible Spectrophotometer
I.R. Spectrophotometer
Fluorimeter
Polarimeter
Mass Spectrometer
Weight Scale
Soil Probe

design which would result in an optimum instrument. In the following discussion each instrument is described in the same order it appears across the top of the matrix given in Table 5-II. Where it is pertinent, schematic diagrams, sketches, or drawings are also shown to illustrate the instrument.

a. Thermometer. There are a variety of types of temperature measurements required in the experimental procedures covering in some cases a large dynamic range and in others a small range with high precision. Fortunately, there are also a large variety of sensors available in solid state devices such as thermocouples, thermistors, and resistance wire elements which are capable of performing this measurement over a large range, have a linear output, are insensitive to dry-heat sterilization, and can be miniaturized as required. The only requirement associated with these devices is that a thermally stable reference at a known temperature is necessary to obtain quantitative results. The most reliable reference would be a solid state device which would be insensitive to changes in gravitational forces and pressure. For this purpose a high heat capacity mass such as copper heated by a resistance element is proposed. Bimetallic switching elements can be used to control the heat input. Insulating the mass will reduce power consumed and damp out the influence of external environmental changes. A temperature reference unit configuration is shown in Figure 5-1.

b. Atmospheric Parameters Sensor. This instrument is designed to measure dynamic pressure due to wind, static atmospheric pressure and atmospheric temperature. The basic instrument consists of a pitot-static head which is similar to that used on aircraft to obtain velocity. The basic elements are shown schematically in Figure 5-2. Dynamic pressure is determined by the deflection of two membranes which are exposed to dynamic pressure on one surface and static pressure on the other surface.

Analysis indicates that an aluminum membrane two inches in diameter and 0.001 inch thick will deflect the amounts shown below for the velocities shown in a 10-millibar atmosphere.

Velocity	Deflection
10 fps	0.00075 in.
300 fps	0.00720 in.

It is feasible to measure deflections of this magnitude using either optical or electrical methods. The simplest method would be to use the two membranes as a parallel plate capacitor. The capacitance is given by $C = KA/d$. Since the dynamic pressure is proportional to the square of the velocity and the deflection of the plate is proportional to the cube root of the pressure, the change in capacitance will be inversely proportional to velocity to the two thirds power. If an initial spacing of 0.010 inch is used, the capacitance will decrease by 59 percent at the maximum wind velocity and 13 percent at 10 feet per second. The response for this system is shown in

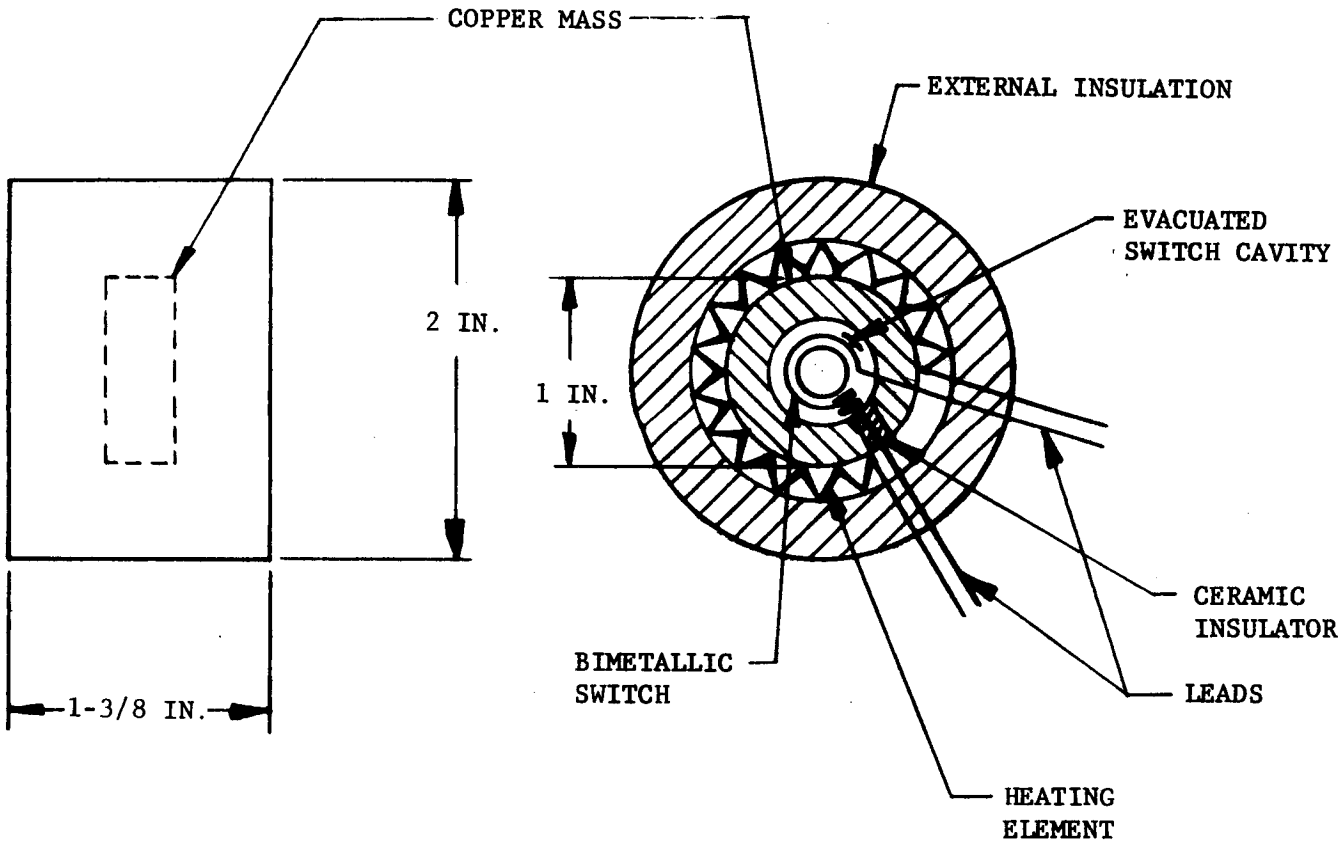


FIGURE 5-1. TEMPERATURE REFERENCE UNIT CONFIGURATION

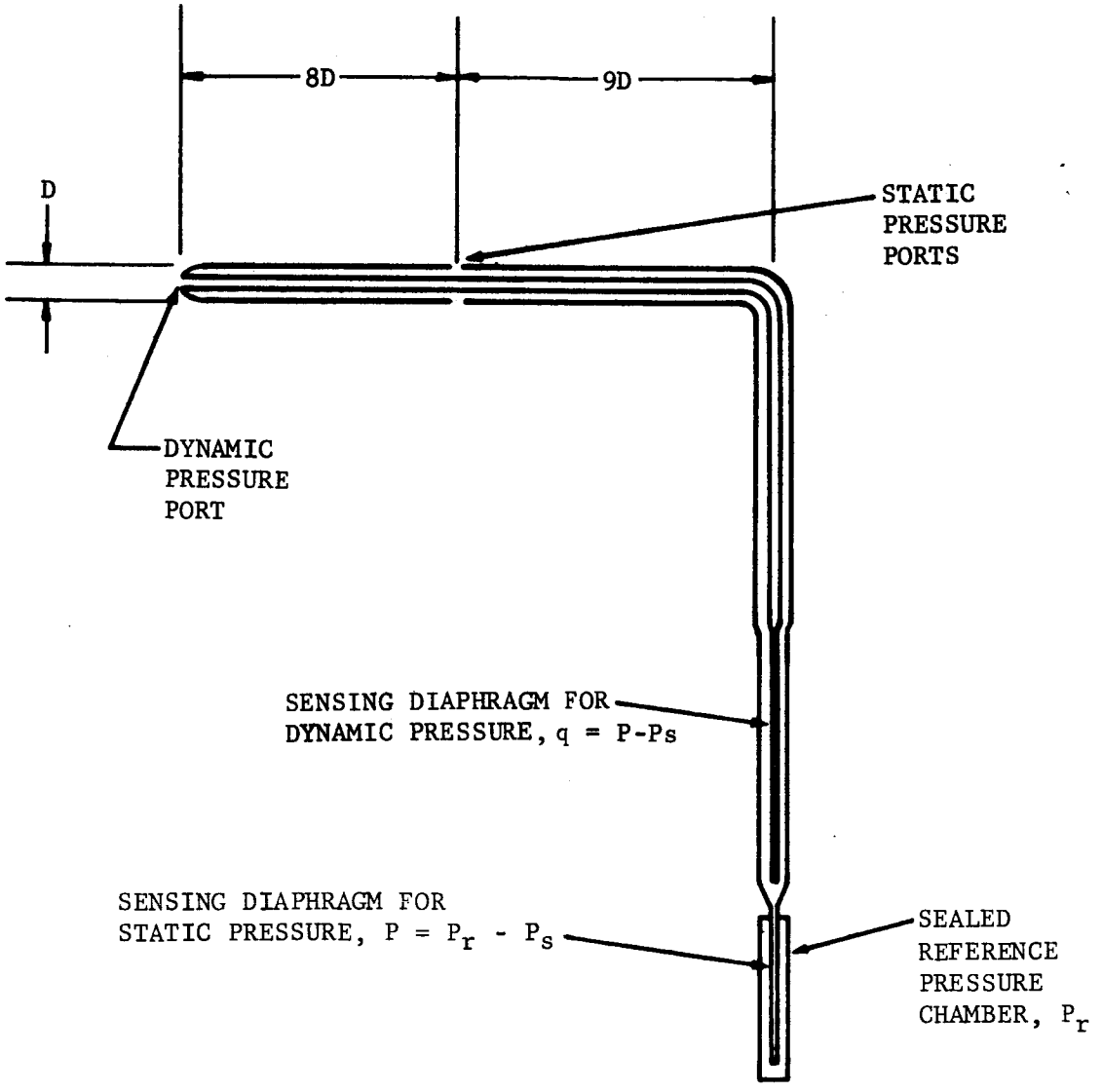


FIGURE 5-2. SCHEMATIC PITOT STATIC HEAD

Figure 5-3. To achieve sensitivity at the low velocities and also to provide a means of sensing wind direction, hot wire anemometers are used. These are located in pairs on either side of the support mast for the pitot tube as shown in Figure 5-4. The differential output of these can be used to servo drive the pitot head to point into the wind. The performance of a standard pitot tube is shown in Figure 5-5 to stay within a one percent error at yaw angles up to seven degrees. These yaw angle tolerances can easily be met with the sensing and servodrive system.

The remaining parameter to be sensed is the absolute level of static pressure. Referring again to the schematic in Figure 5-2, the static pressure from the pitot tube can be vented to another set of diaphragms housed in a sealed chamber with a predetermined pressure. The pressure in the sealed chamber can be set at a value near the range of expected pressures, say 30 millibars, in such a manner that it will produce no deflection when the vented pressure is 30 millibars. Since the deflection of a membrane is proportional to the cube of the pressure, a response curve such as shown in Figure 5-6 is obtained. It is seen that the sensitivity is best near the reference pressure but falls off less rapidly when the reference pressure is higher than the measured pressure. The response curves shown have not been optimized but are used to indicate feasibility of the method. The range of parameters measured are:

Ambient temperature	$-150^{o}C$ to $38^{o}C \pm 1$ percent
Static pressure	2 mb to 100 mb
Wind velocity (pitot tube)	10 fps to 300 fps $\pm$ 10 percent
(hot wire)	0 fps to 15 fps $\pm$ 1 percent
Wind direction	To nearest 5^{o}

c. Gold Film-Aluminum Oxide Water Vapor Detector. This detector is similar to one developed under JPL Contract 950684, 31 December 1964, by Parametrics, Waltham, Massachusetts. The change in resistance caused by water vapor absorbed by the aluminum oxide layer is measured. A sensitivity that will detect water vapor to a partial pressure of 10^{-5} mm H_g is expected. The change in resistance can be determined using a bridge circuit. Typical configurations are shown in Figure 5-7.

d. Microphone with Resonator. This instrument serves to identify the frequency of impact of blown sand particles. The principal employed in micrometeroid detectors in which a microphone is mounted on a resonating plate will be used to monitor particle movement up to some given threshold level. For the laboratory configuration studied the outer skin of the laboratory is used as the resonating plate with microphones mounted on the

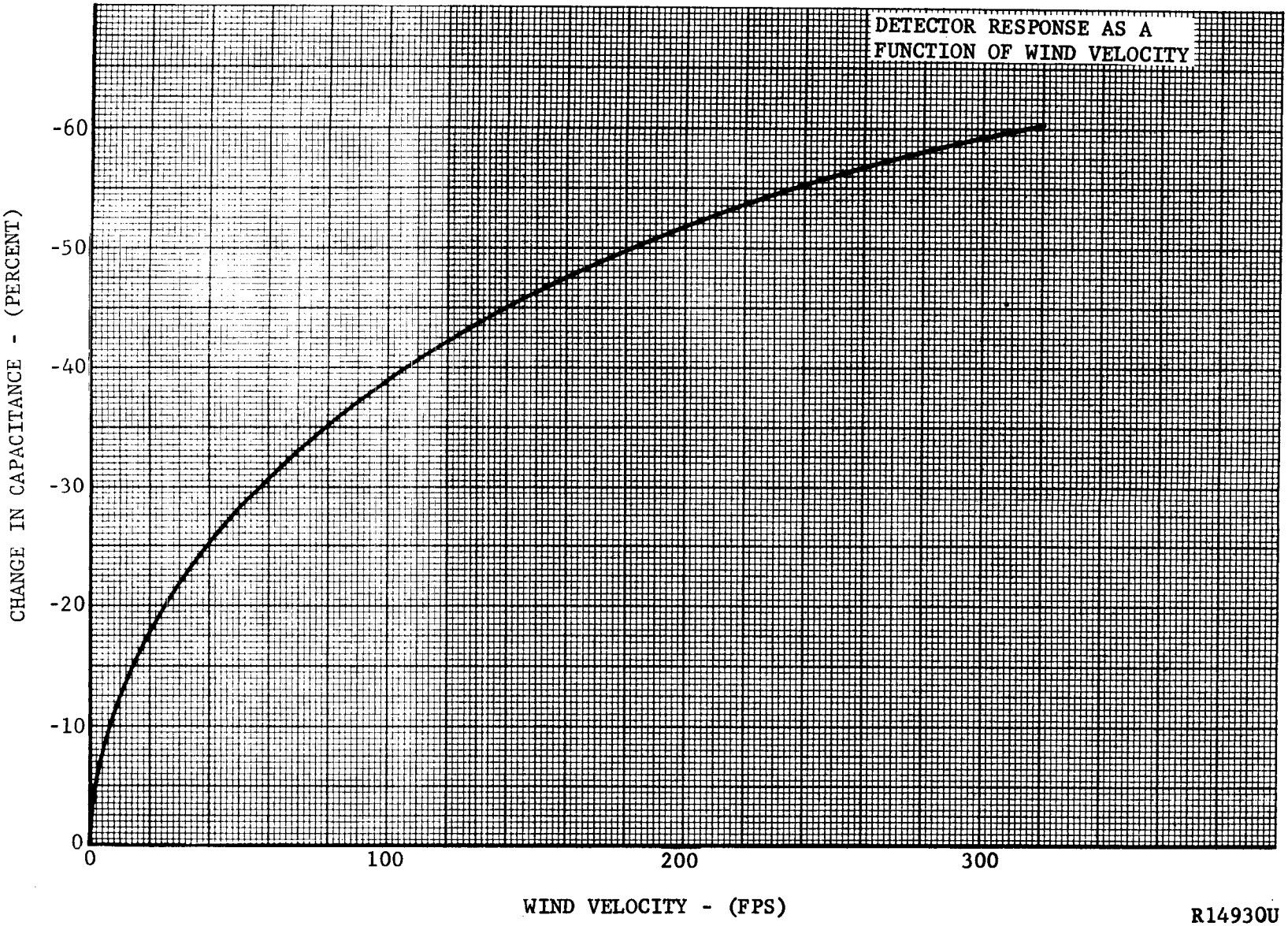


FIGURE 5-3. DETECTOR RESPONSE AS A FUNCTION OF WIND VELOCITY

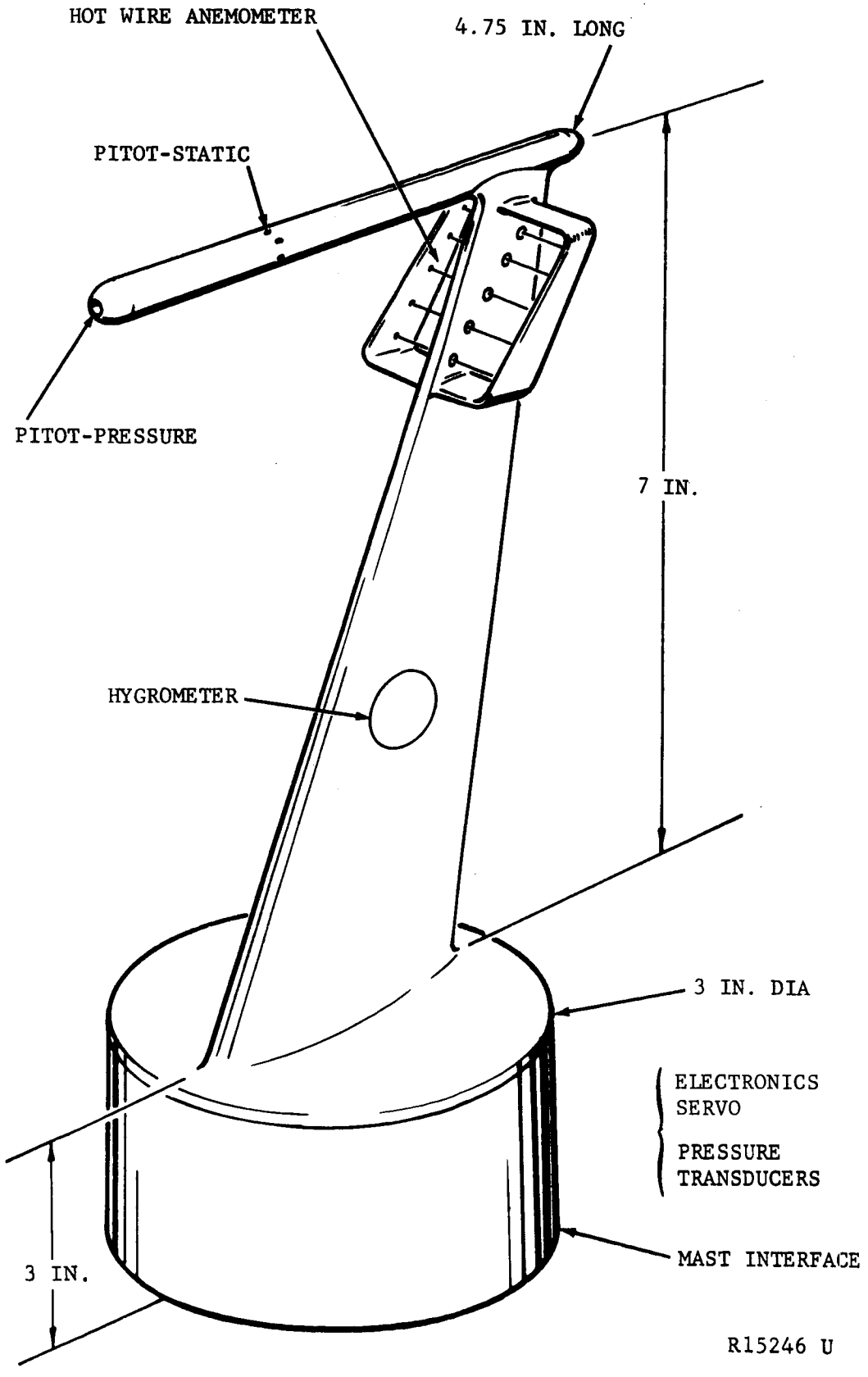


FIGURE 5-4. MAST HEAD INSTRUMENTS

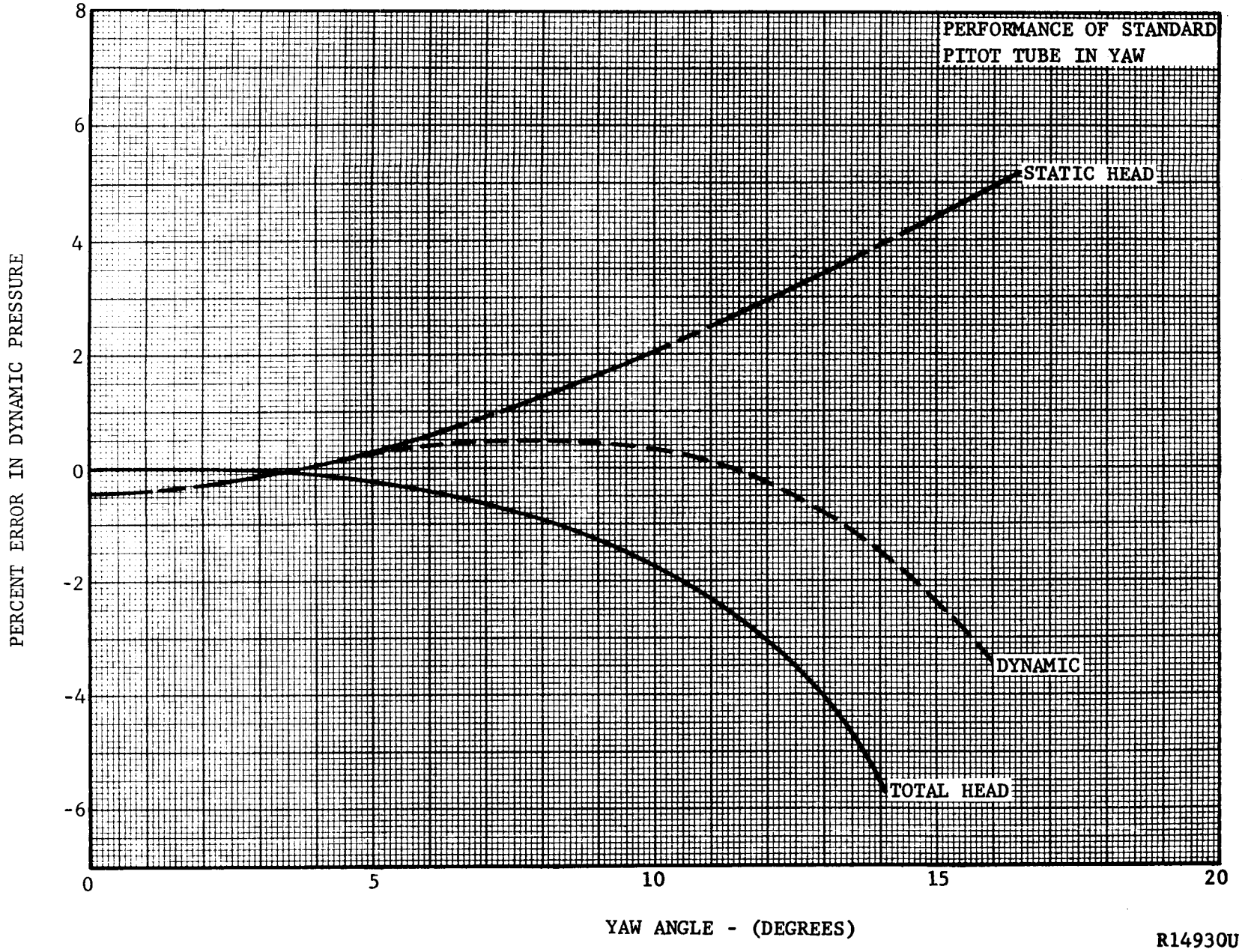


FIGURE 5-5. PERFORMANCE OF STANDARD PITOT TUBE IN YAW

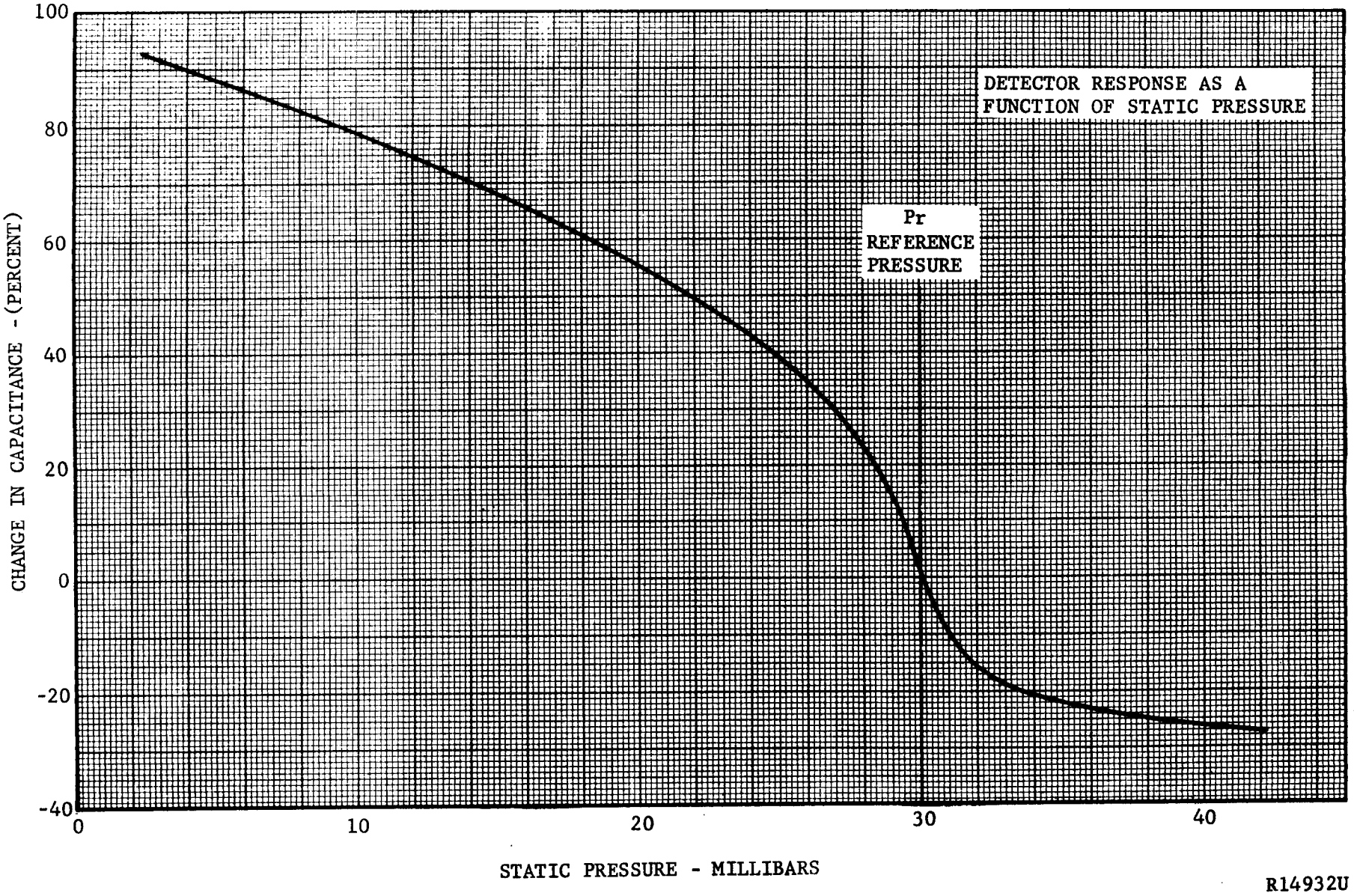
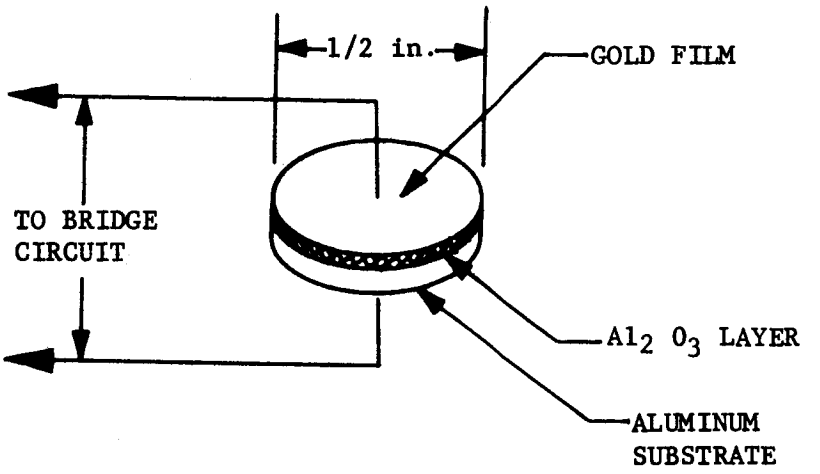


FIGURE 5-6. DETECTOR RESPONSE AS A FUNCTION OF STATIC PRESSURE



DISK CONFIGURATION

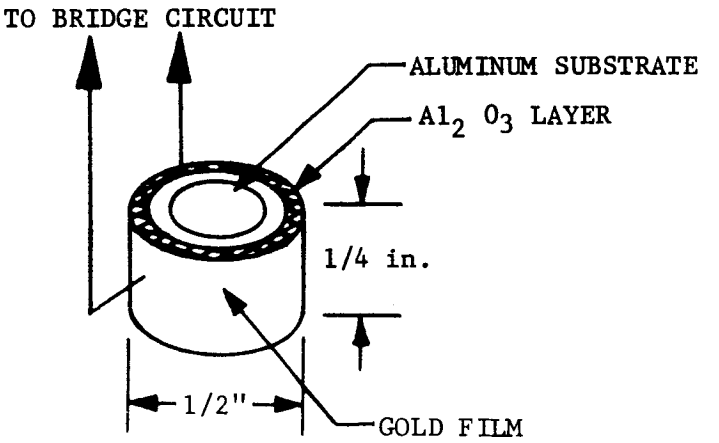


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FIGURE 5-7. CYLINDRICAL CONFIGURATION

inner surface. This location is chosen to keep them near the surface since most of the particle movement occurs below a height of a few meters. To perform a quantitative survey of wind transported particulate matter, a pneumatic tube connected to the cyclone collector, used during soil grading, will be capable of collecting particles at various levels above the surface. The weight scale incorporated in the collector will be used to determine the amount of soil particles being transported.

e. Omnidirectional Microphone. There are a large variety of sensitive microphones available to monitor acoustic sounds. Since analog transmission from Mars to Earth would be meaningless, the output of the microphone is fed to a frequency analyzer. This analyzer is composed of band pass filters covering the range from 20-2000 cycles per second in 25 bands with a bandwidth of ± 5 percent of the median frequency. Intensity levels at each frequency will be measured in decibels above a reference sound pressure level of 0.0002 microbars up to a maximum of 150 decibels.

f. β and γ-Ray Counter. This counter is used to determine background radiation levels incident at the surface and scattered from the surface. To accomplish this, pulse height counters that can discriminate between β-rays and γ-rays having a 2π field of view are desired. A possible configuration is shown in Figure 5-8. The detector consists of 3 pulse height counter tubes shielded against penetration by β particles and one tube with a thin window which will allow both β and γ particles to penetrate. Thus, all the tubes will sense γ particles and only one will sense β particles. The counter tube array is shielded with tungsten so that it will view a field of 2π steradians. The assembly is mounted on a parallel arm linkage so that it may be held near the surface or several feet above the surface and parallel to the surface. In performing a background radiation count the detectors are deployed facing the sky about a meter above the surface to determine incident radiation. After determining the incident radiation, the detectors are rotated 180 degrees and oriented near the surface to determine the background radiation scattered from the surface.

g. Core Hole Sonde. This instrument is essentially the design developed by Texaco Experiment, Inc., Richmond, Virginia, for use on the lunar surface as reported in their report TEJ-46, 1 March 1963. The only differences are that the thermal diffusivity and acoustic velocity measurements have been deleted and water vapor detectors have been added. This instrument is shown in Figure 5-9. Subsurface temperature is determined by both a modified Michelson interferometer and resistance thermometers. Soil electrical conductivity is measured by determining the electrical potential drop between two points of contact in the core hole and can also be inferred from the subsurface magnetic susceptibility instrument. Soil density is determined by the γ-ray scattering characteristics of the soil.

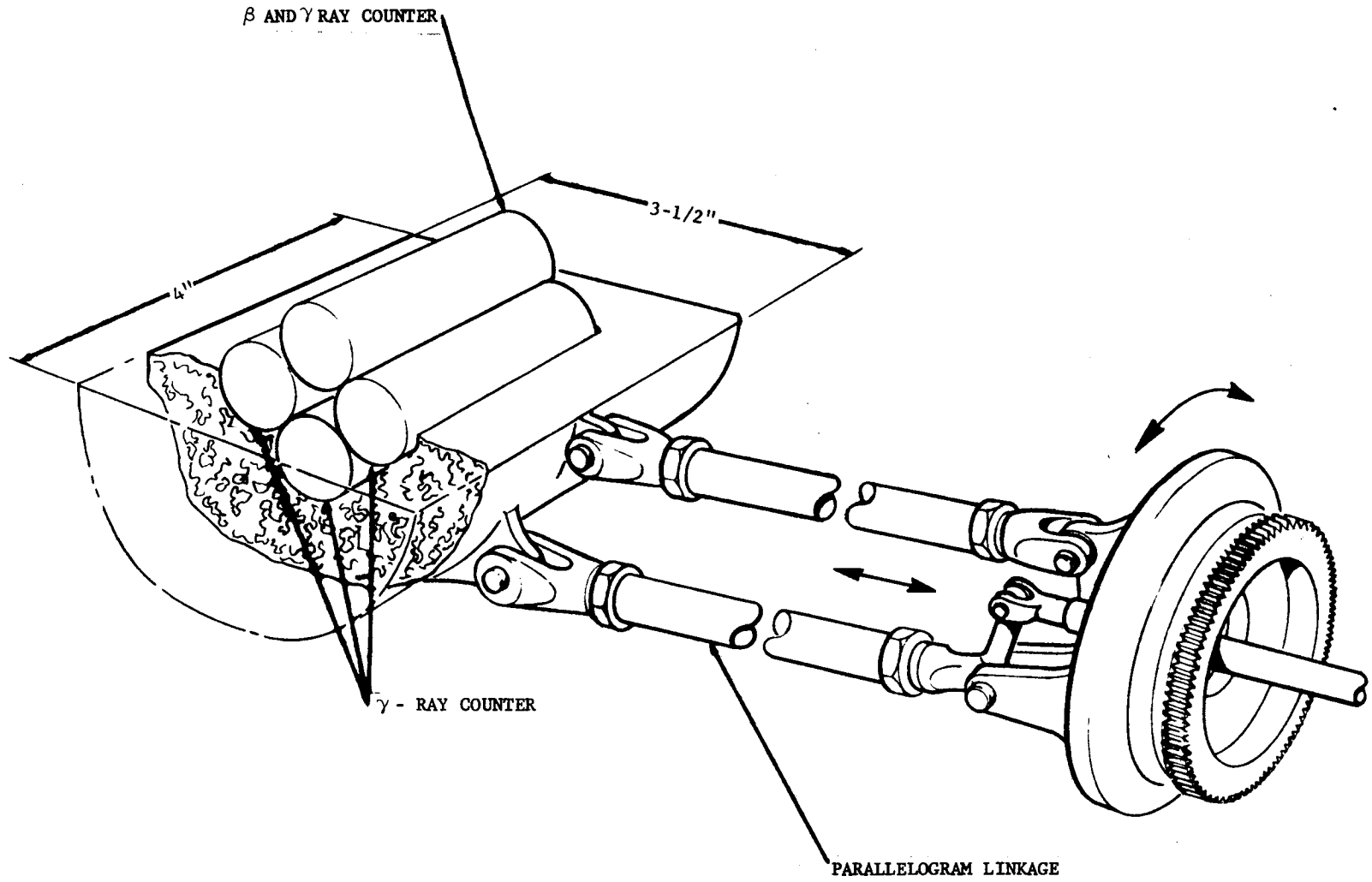
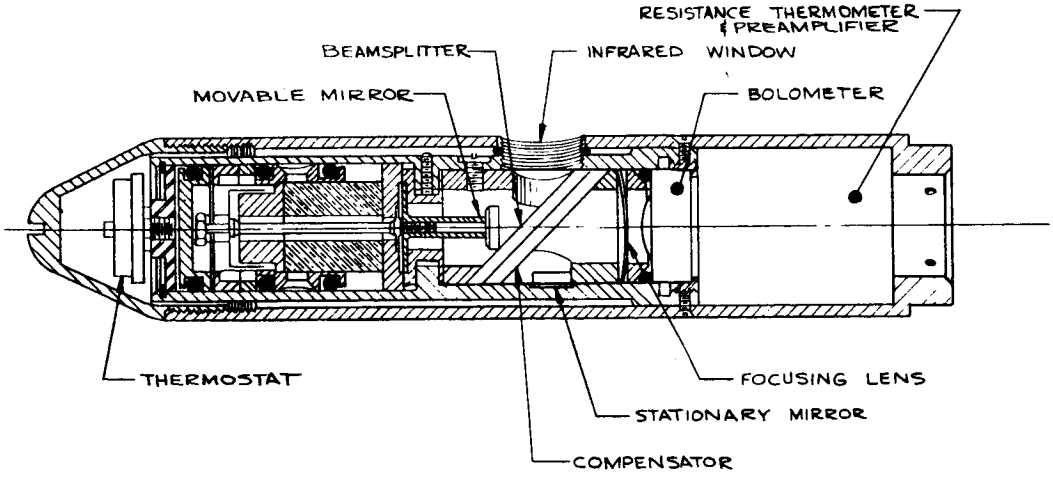


FIGURE 5-8. β AND γ RAY COUNTER ARRAY

h. Soil Mechanics Apparatus. This apparatus is combined in the structure of the soil sample collector and is shown in Figure 5-10. When the soil sample collector is placed on the surface, pressure sensitive sensors mounted in the face of the sampler support structure will indicate continuity of contact By applying vertical force on the sampler body it will be forced into the soil yielding load sinkage data. If no sinkage occurs and complete continuity is not achieved, then the surface will be considered to be hard rock. A flange mounted externally on the body increases the contact area after a fixed penetration is achieved, thereby yielding load sinkage data for a larger footprint area. From the two sets of load sinkage data the soil characteristics are determined in terms of a cohesive constant k_c and an internal friction constant k_ϕ. These are described in Experiment 11 of Appendix 5, Volume 6. The force is applied by means of the deployment boom for the sampler used at the laboratory site. The remote sampler uses a pyrotechnically fired stake to fix it to the surface and react the applied force. A motor drive is used in this case to apply the requisite force.

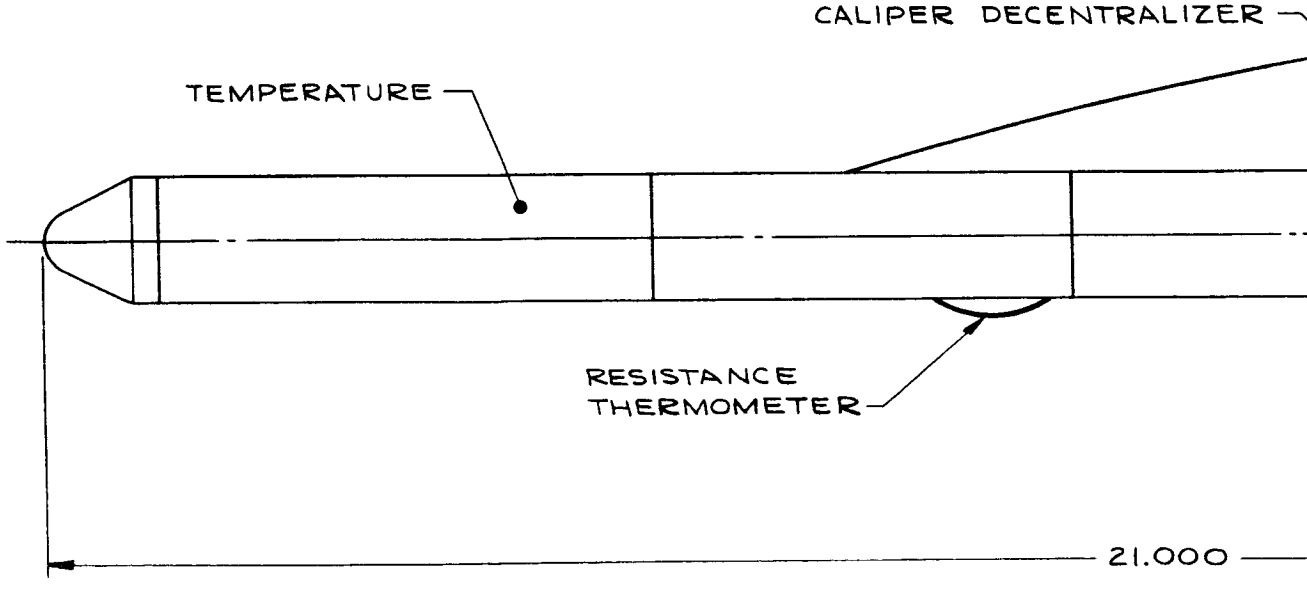
i. Optical Motion Detector. This detector is designed to provide a field of view covering the same area viewed by the visual and infrared detectors. In the event that motion is detected, the results of the three scans can be cross-correlated. A schematic of the optical system for this detector is shown in Figure 5-11. The detector has no mechanically moving parts and consists of an annular mirror which focuses the image on a ring detector matrix of photosensitive material similar to that used in solar cells. The resulting image is distorted with this system, but should be sufficiently good to detect motion. This type of annular mirror has been used in submarine periscopes to provide a peripheral 360-degree field of view around the primary image so the entire horizon can be scanned without moving from the primary image. Motion is detected by sensing the rate of change of output from an element in the matrix and correlating it with the sequential output of adjacent sensor elements.

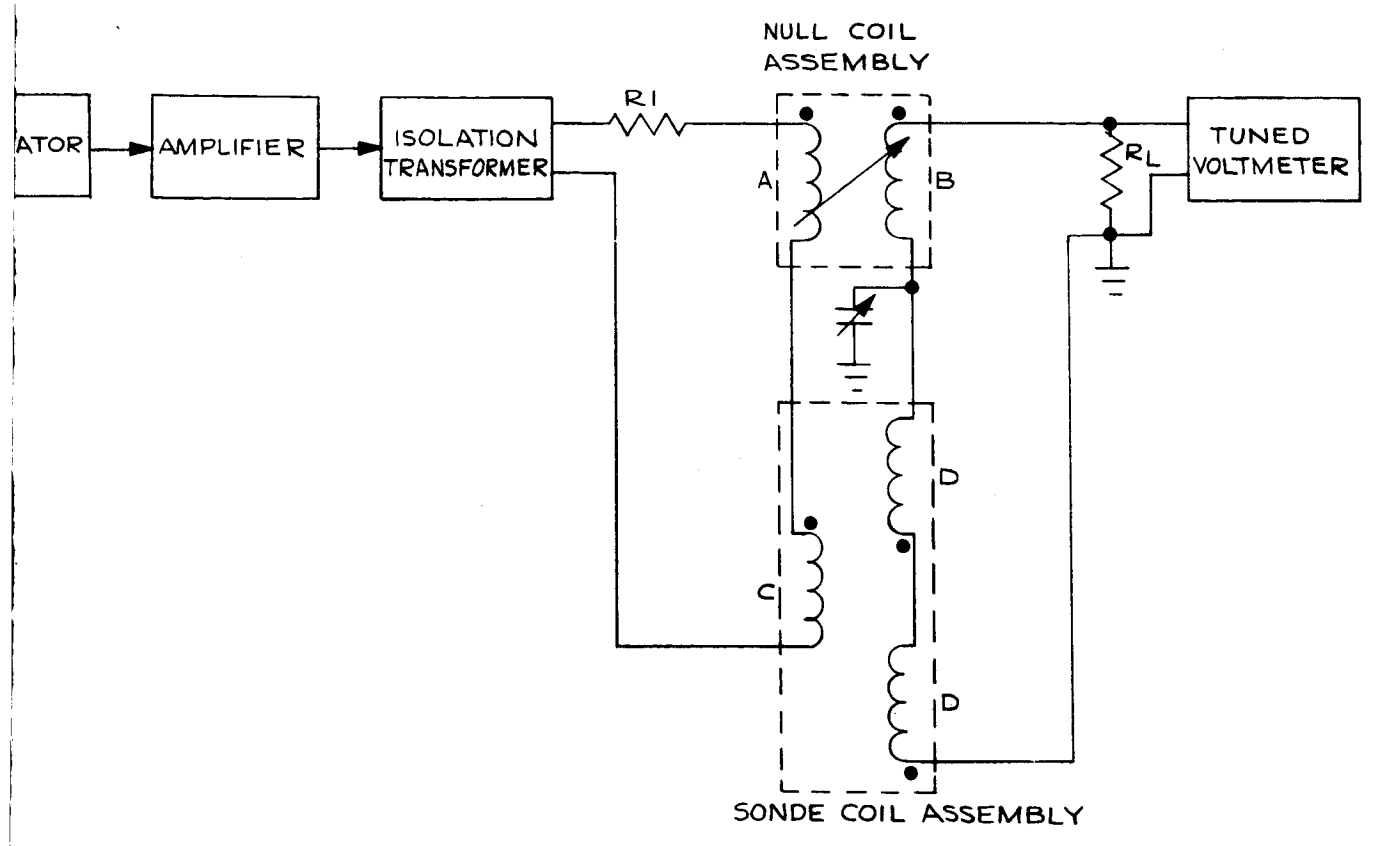
j. Macroimaging System - Infrared Radiometer - Solar Insolation Radiometer. These three items are described together since they are intended to operate as a single unit. The visible picture can be taken with either a television camera or a facsimile scanning system. On the basis of its potential high resolution and ability to provide an infrared scan, the facsimile system is used in the preliminary design of the instruments. The system in shown in Figure 5-12. In this system a visible and I.R. dual optical system view 180 degrees apart and share a common rotating scanning mirror. The optical branch operating in the visible spectrum utilizing fused silica optics which will give it the capability of covering the spectrum from 250 mμ to 2μ. The optical branch operating in the infrared spectrum uses synthetic sapphire optics such as Kodak's Irtran with the capability of covering the spectrum from 2μ to 14μ. Typical spectral transmission curves for these materials are shown in Figure 5-13. By positioning the rotating scanning mirror at any angle up to a view angle of



OSCILL

SUBSURFACE TEMPERATURE INSTRUMENT ASSEMBLY DRAWING
NO SCALE





MAGNETIC SUSCEPTIBILITY INSTRUMENT
BLOCK DIAGRAM

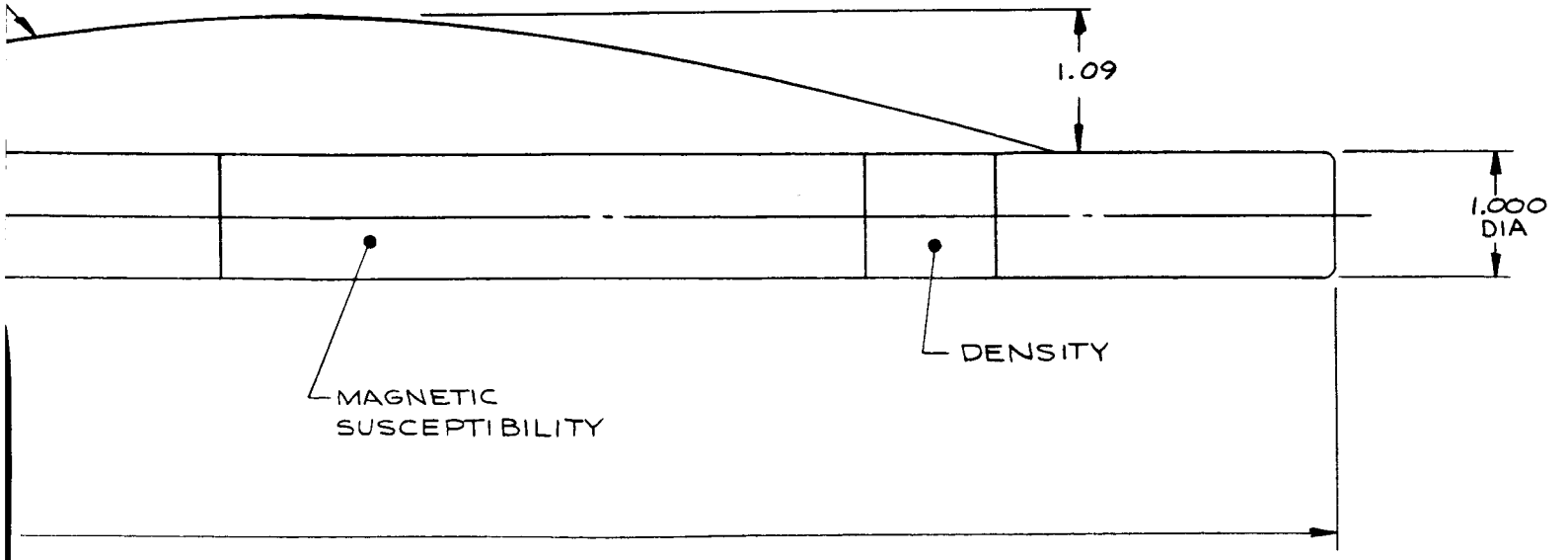


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FIGURE 5-9. SUBSURFACE TEMPERATURE INSTRUMENT ASSEMBLY

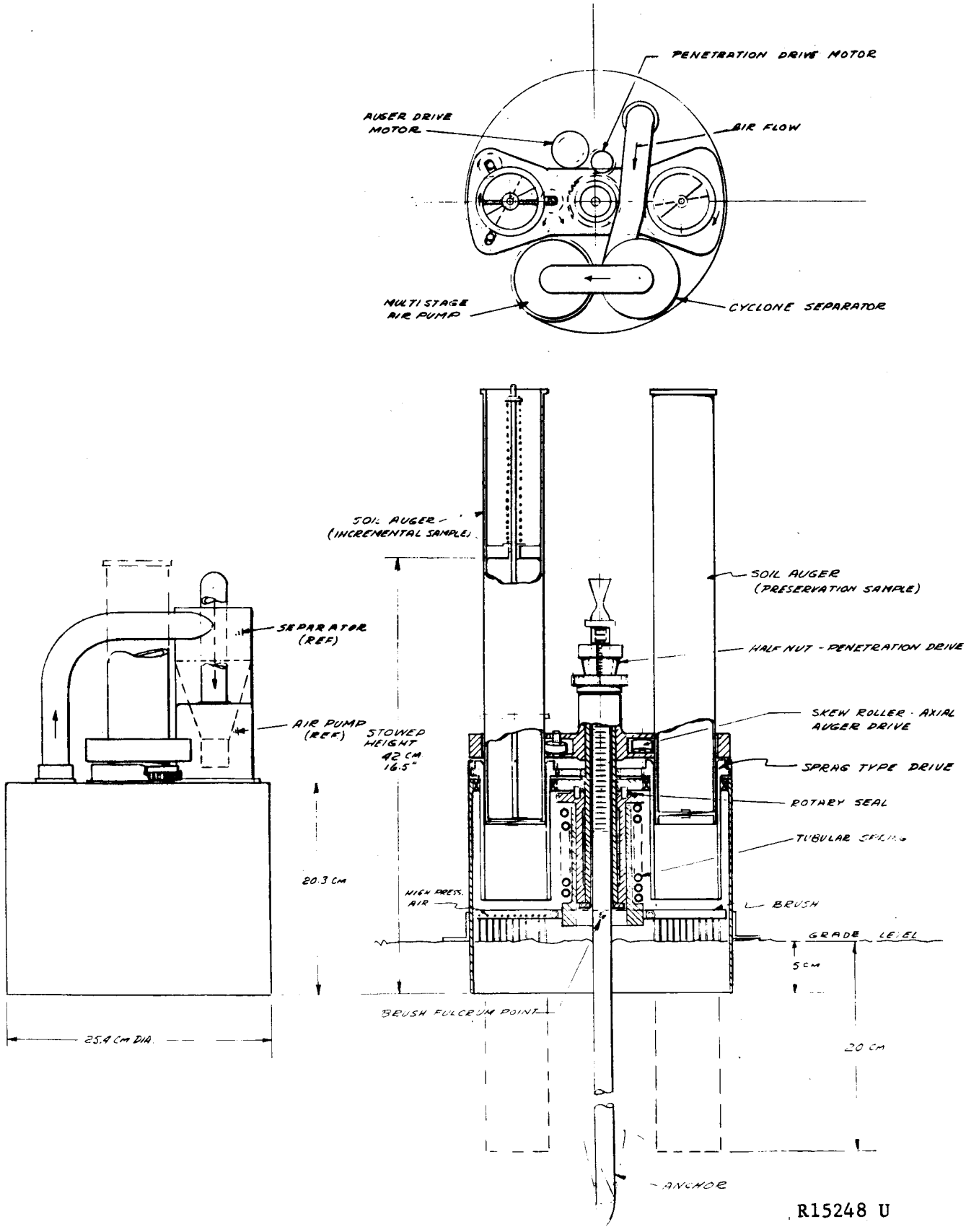

FIGURE 5-10. SOIL MECHANICS AND SAMPLING MECHANISM

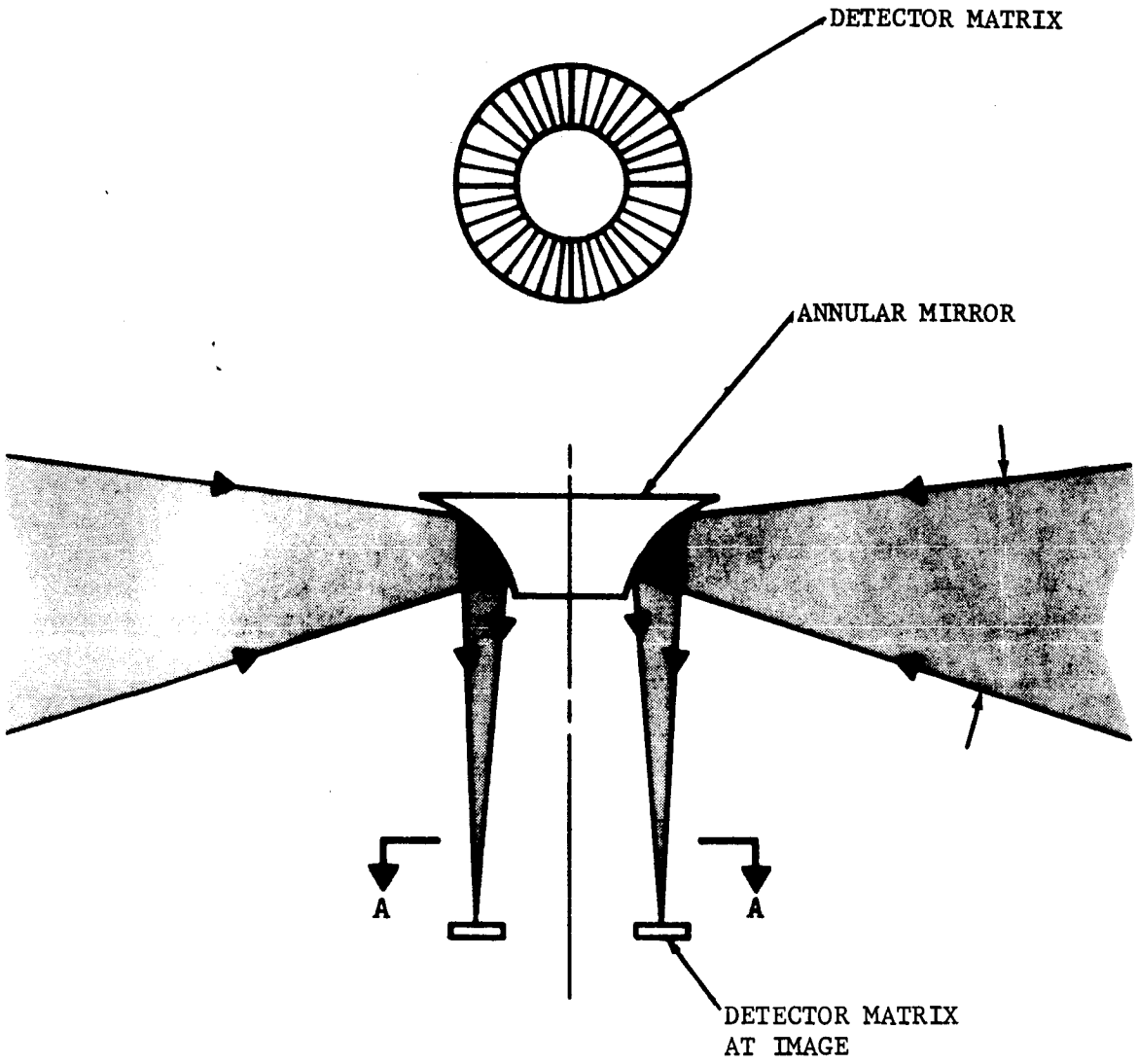

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FIGURE 5-11. OPTICAL MOTION DETECTOR

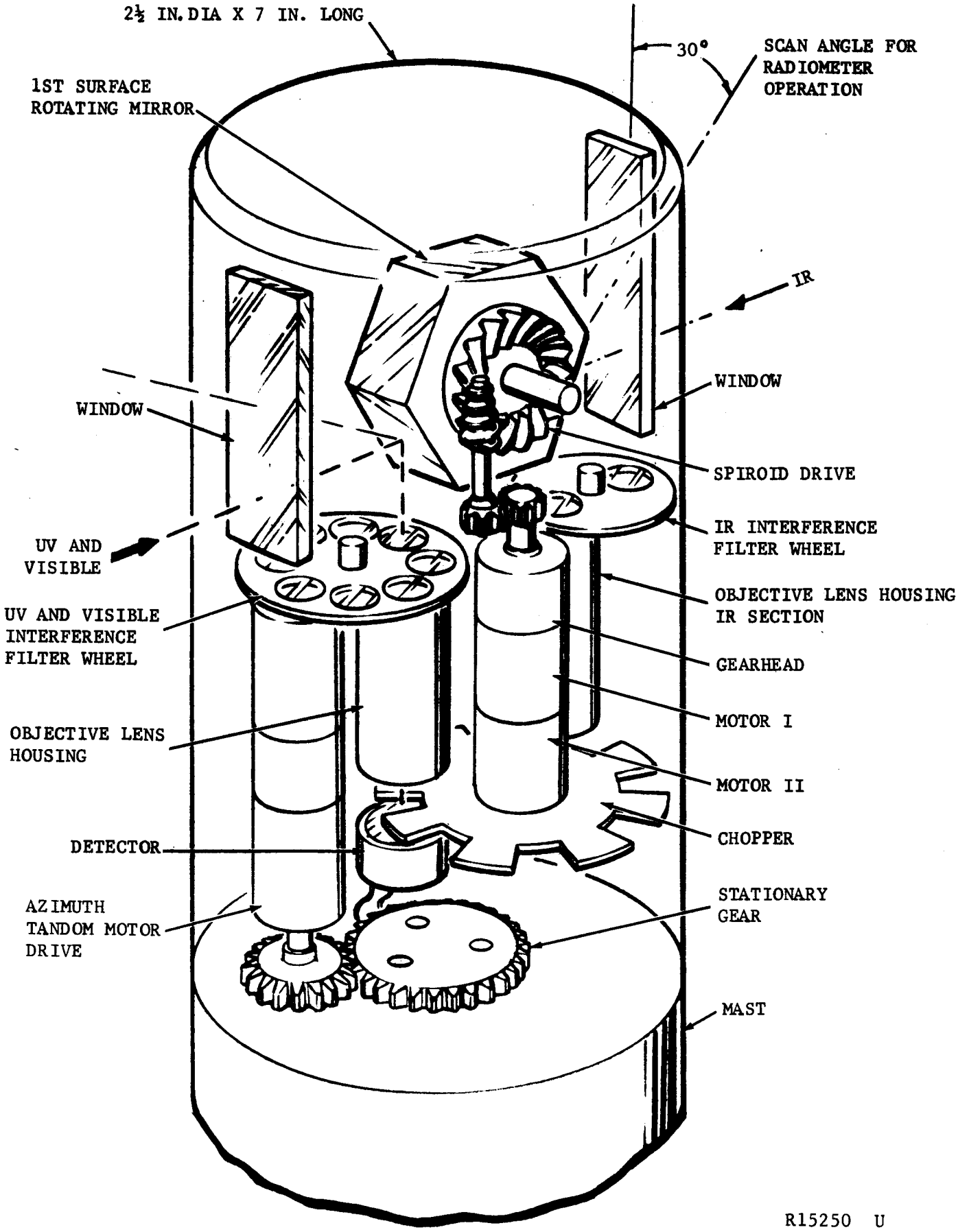

FIGURE 5-12. MACROIMAGING SYSTEM - IR AND SOLAR INSULATION RADIOMETER

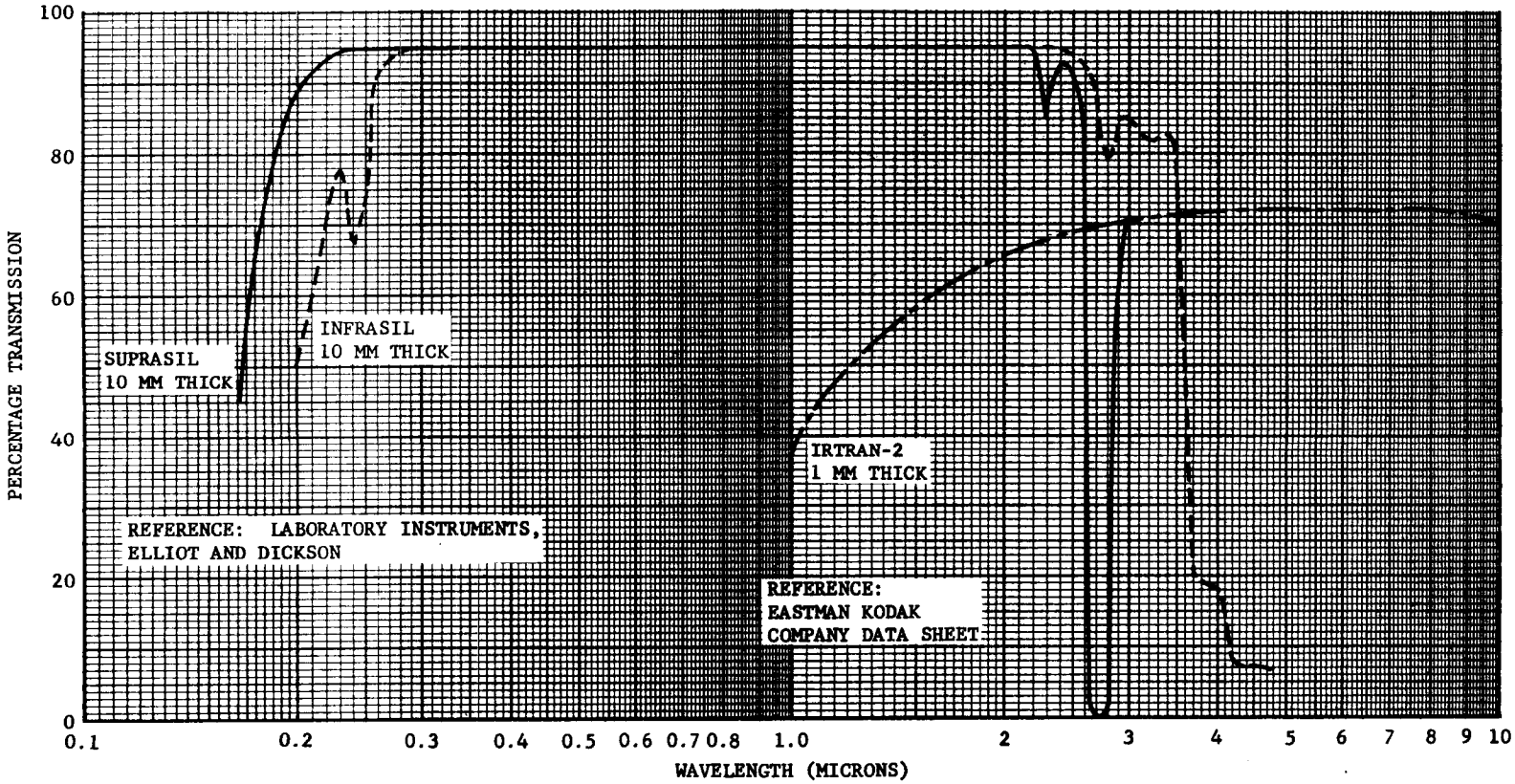

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FIGURE 5-13. TRANSMISSION CHARACTERISTICS OF FUSED SILICA AND SYNTHETIC SAPPHIRE

30 degrees from the vertical and positioning interference filters in position in front of the objectives, this instrument can also be used as a solar insolation radiometer. By traversing the view through 360 degrees and scanning at several angles from the vertical an integrated spectrum can be obtained. The range of wavelengths scanned is divided into discrete bandwidths as listed below.

Frequency Range	Bandwidths Scanned
250 mμ to 350 mμ	3
350 mμ to 700 mμ	4
700 mμ to 2μ	1
2 μ to 14 μ	2

k. pH Meter. This instrument is used to measure the relative acidity of a solution by determining the free hydrogen ion concentration. Hydrogen electrodes have been miniaturized to the extent that they may be implanted in a vein. Thus, the primary concern in the usage of these electrodes in the ABL is to determine where it is used and how to mount it. There are only two pieces of equipment used where pH measurements are made. These are in the chemical processor and in the culture evaluation chambers. The probes used in the culture evaluation are considered to be built into the dish holding the culture to be evaluated. The probe used in the chemical processor is mounted in an adapter which will allow it to be positioned in the chemical processing chamber with the ampule feed mechanism and is shown in Figure 5-14.

l. $Ba(OH)_2$ Conductivity Cell. This sensor functions on the basis that the electrical conductivity of $Ba(OH)_2$ will vary in proportion to the amount of carbon dioxide absorbed in the barium hydroxide solution. This sensor is used only in Experiment 30 requiring a total of 240 measurements in the 2-year lifetime of the laboratory. Since the $Ba(OH)_2$ must be renewed or replaced after each usage, and only small quantities are required, this sensor is designed as a throw-away unit. Experiment 30 is performed in the chemical processing chamber so that the $Ba(OH)_2$ sensor can be constructed as a modified ampule as shown in Figure 5-15.

m. β-Ionization Detectors. Two variations of β-ionization detectors are required as sensors in the ABL instrumentation. Experiments 17, 29, 31, and 32 requires a standard β ionization chamber as shown in Figure 5-16. This is also configured to be compatible with the ampule feed mechanism. Experiment 13 requires the use of an argon β ionization detector which is shown in Figure 5-17. The argon β ionization detector varies primarily in construction details and requires a radioactive source. These detectors both work on the principle that a small current will flow between two plates,

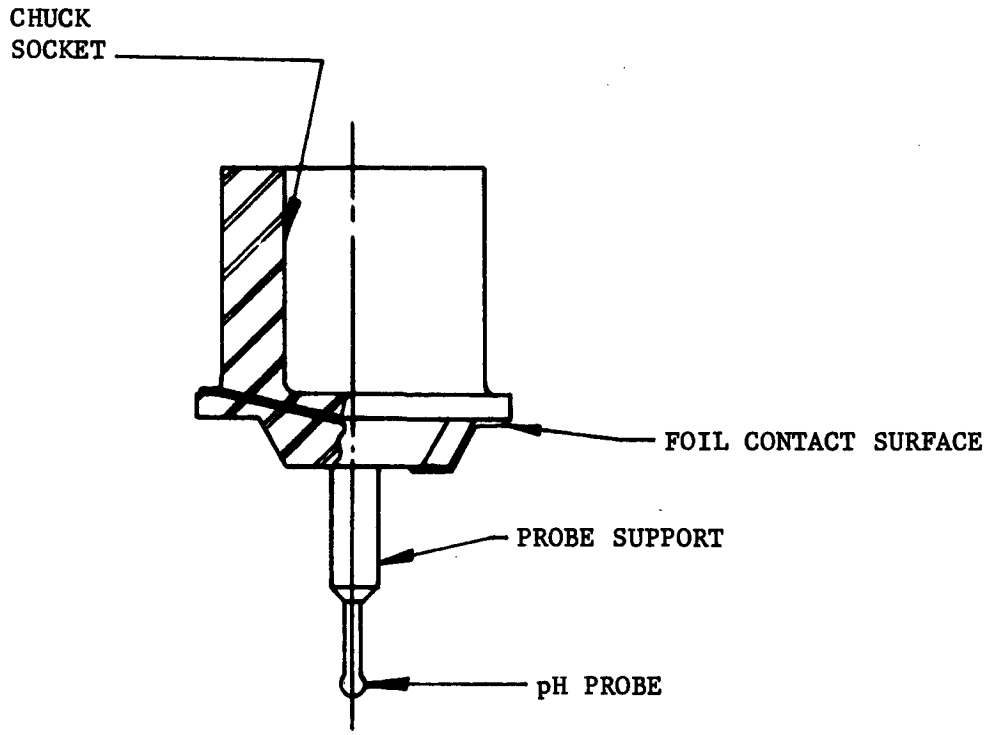

FIGURE 5-14. pH PROBE FOR CHEMICAL PROCESSOR

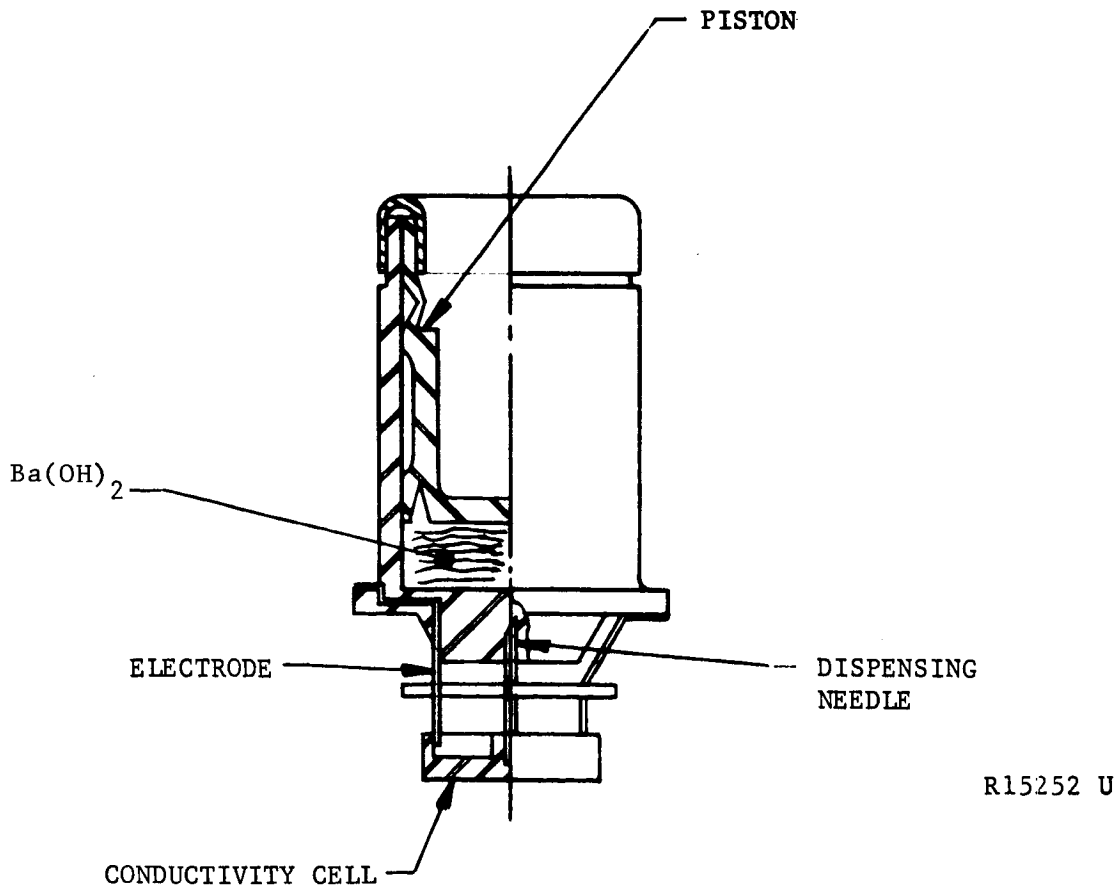

FIGURE 5-15. $Ba(OH)_2$ CONDUCTIVITY CELL

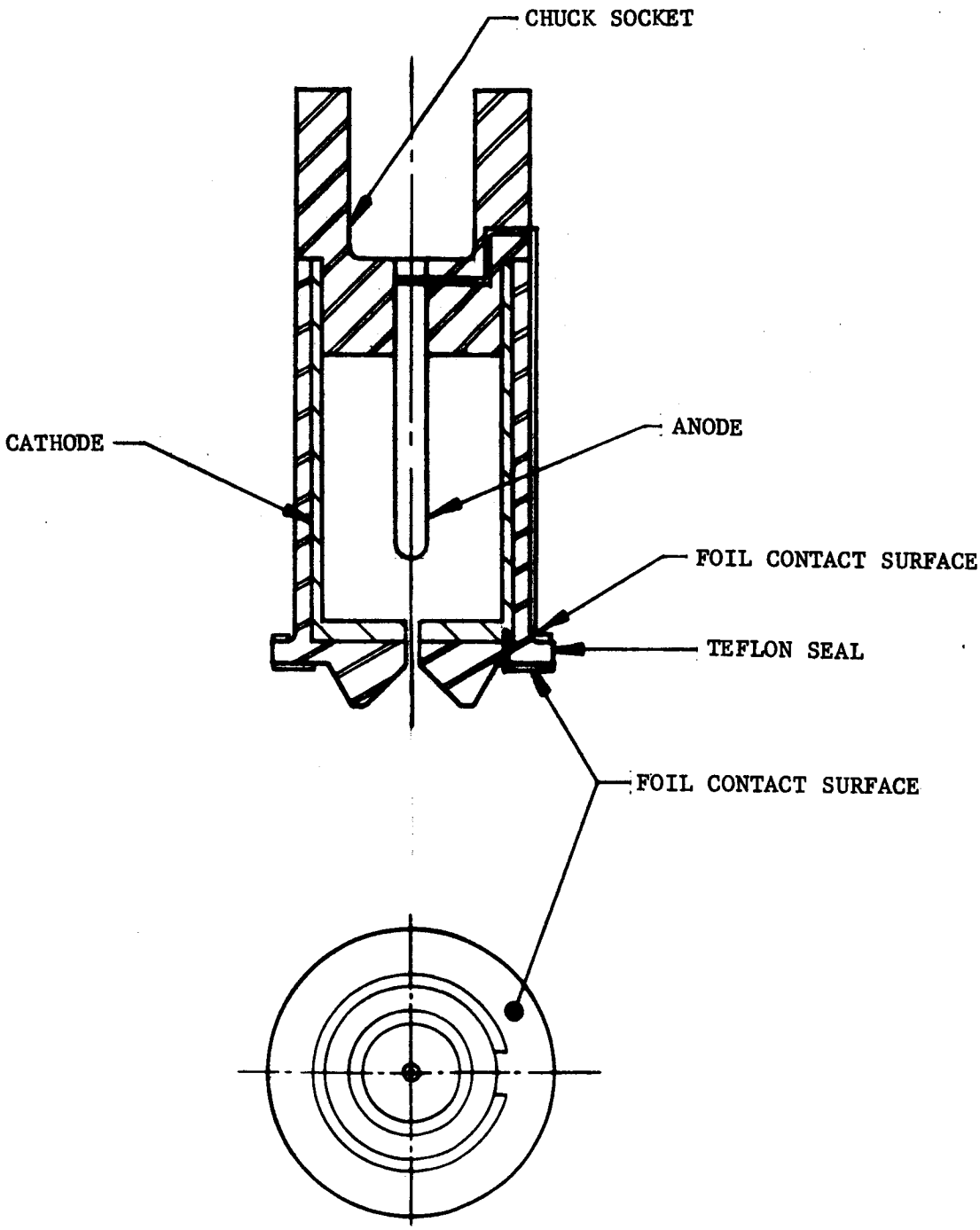

FIGURE 5-16. β IONIZATION CHAMBER

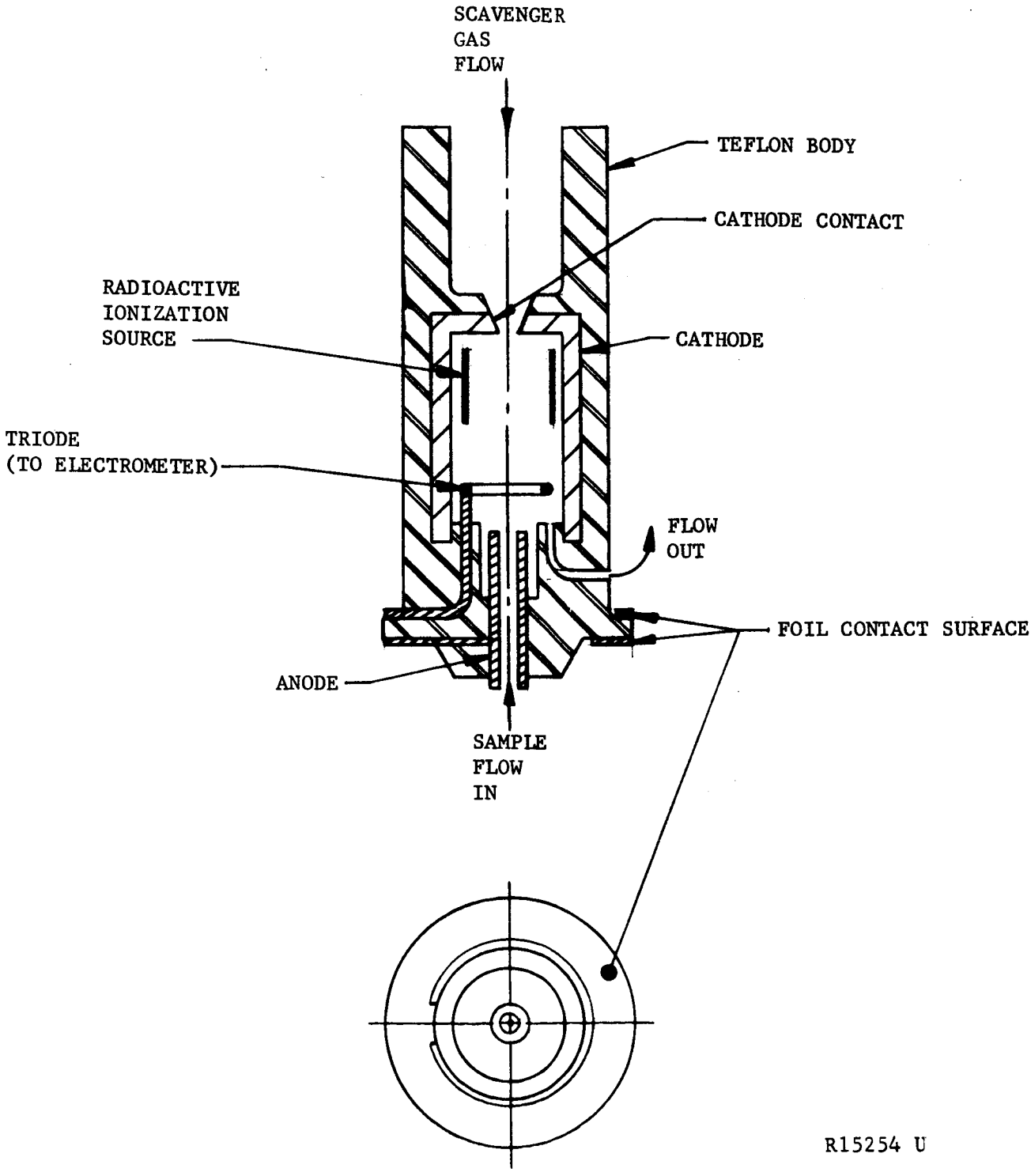

FIGURE 5-17. ARGON β IONIZATION DETECTOR

between which an electrostatic potential exists, when the gas separating the plates is ionized. The output current is fed to an electrometer which amplifies it to a usable value. The current flow between the anode and cathode is determined by the degree of ionization of the gas and the voltage of the electrostatic field. A typical current output as a function of voltage is shown in Figure 5-18A. The ratio of ionization of a gas with impurities to that of a pure gas is shown in Figure 5-18B. Thus, this principle can be used in two ways, either to count beta particles or to detect impurities in a carrier gas. The detector shown in Figure 5-16 is used to detect gases that carry a tagged radioactive isotope such as carbon 14. The degree of ionization and the current flow is proportional to the concentration of gas carrying a tagged component. In the case where impurities are to be detected, i.e., a sample concentration, the radioactive source in the detector produces a steady low level of ionization in a carrier gas. When the sample is introduced, it acts as an impurity and increases the level of ionization which, in turn, increases the output current.

An effect that occurs is that a space charge builds up at the anode because of the positive ions. This charge will affect the output of the ionization detector. In a cylindrical configuration the outer shell is usually the anode, since it is larger. However, since the output of the detector is nonlinear, a linearizing resistance is used. By making the small center electrode the anode, the buildup of the space charge around it will act as the linearizing resistance. Lovelock found that the relation of the space charge to the anode can be controlled by moving the central anode in and out of its cell along its axis. In practice, linearity is achieved if the end of the anode is several millimeters beyond the end of the cathode and well away from the source of radiation. A further improvement in this type of detector can be made by adding the triode. The advantage of the triode detector is that the background current flows primarily between the anode and cathode. The triode then provides an output current free of background current thus increasing the sensitivity. The use of argon as a carrier gas also increases the sensitivity of the detector, because the argon is excited to a metastable condition by the radioactive source. When a sample is present in the carrier gas it is ionized, causing the argon molecules to return to their normal state, releasing the energy stored in the excited state and resulting in an increase in the output current. Detectors of this type have sufficient sensitivity to detect concentrations as low as 10^{-12} mole.

n. <u>α-Scattering Analyzer</u>. This instrument determines the elemental composition of soil samples and of simple extracts which have been deposited on plates by evaporation. The sample is irradiated with an alpha source and the scattering of α particles from the source is measured. The general configuration of this instrument is shown in Figure 5-19. It consists of a conical section capped with a spherical dome on which solid-state detectors are mounted. The sample is introduced at the apex of the conical section

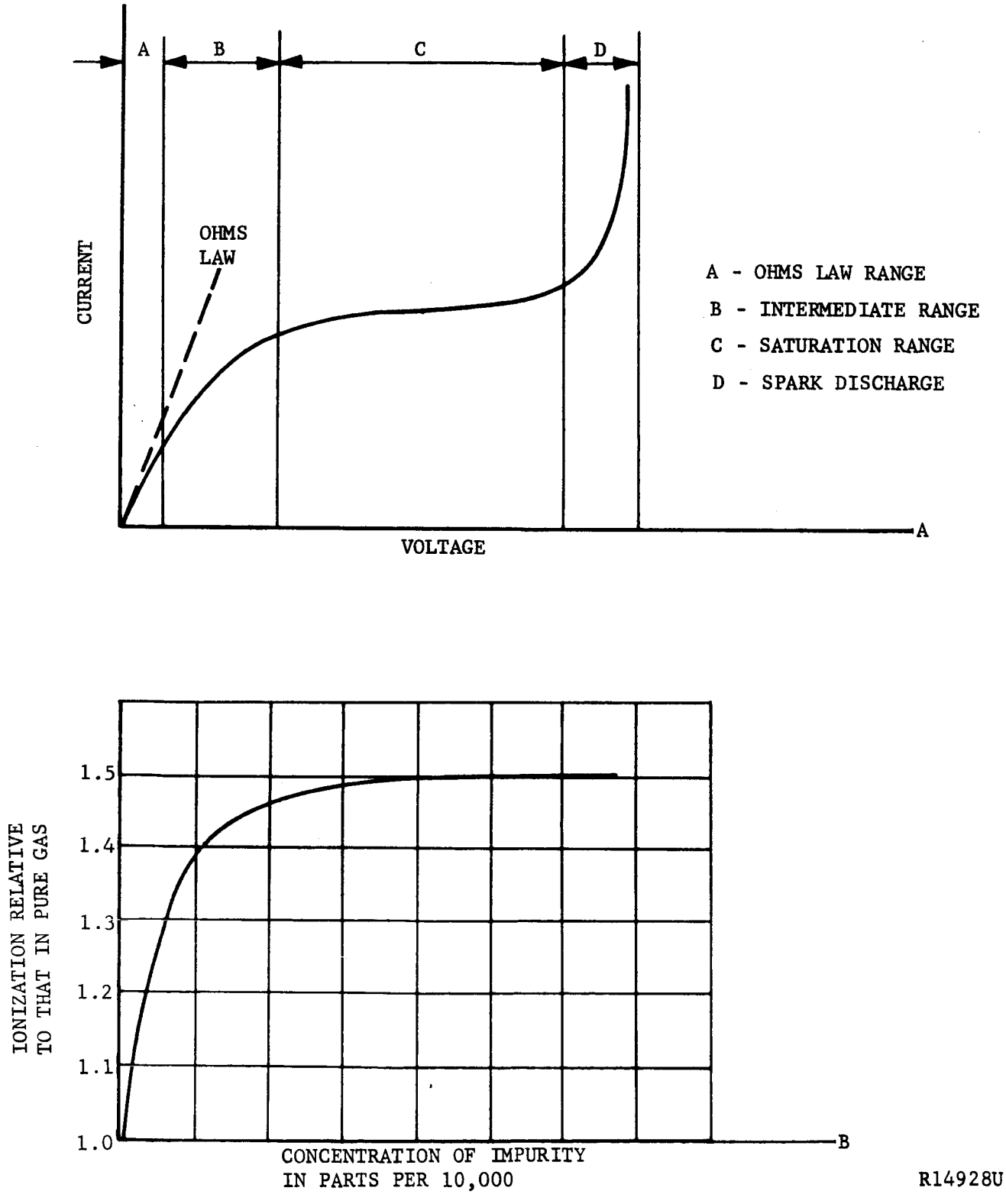

FIGURE 5-18. IONIZATION DETECTOR CHARACTERISTICS

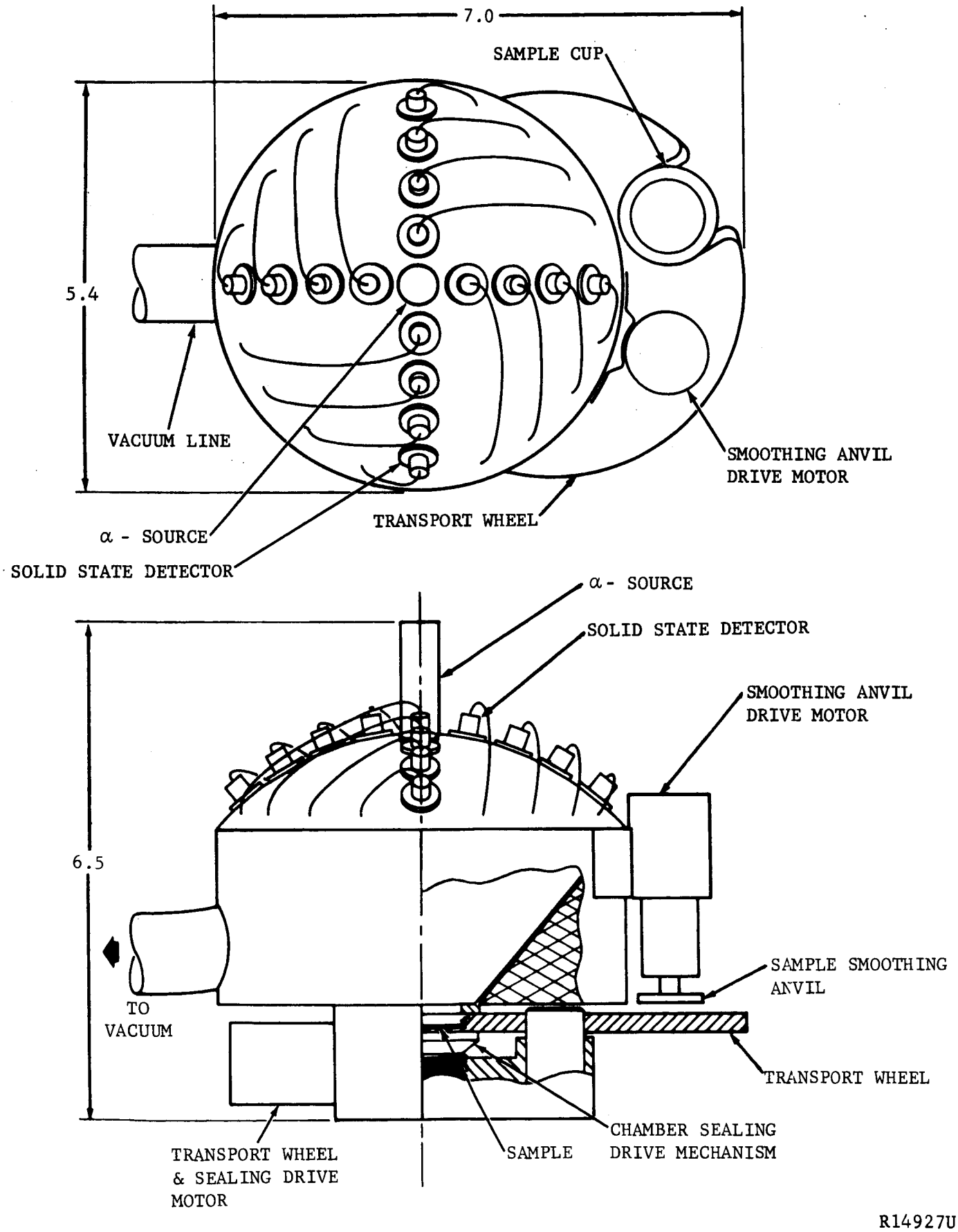

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FIGURE 5-19. α-SCATTERING ANALYZER CONFIGURATION

and the pressure inside is reduced to 10^{-3} mm Hg. The count rate is monitored for a period of 24 hours at each detector to perform the analysis. Raw soil samples which have been processed through the pulverizer are placed in a shallow dish and smoothed with the smoothing anvil to a uniform thickness and surface texture. The anvil accomplishes this by a rotational and compressive motion.

o. Gas Chromatograph No. 1. This gas chromatograph is used to perform the analysis of soil gases and atmospheric gases. A more detailed description concerning selection of the columns and operating characteristics of all the gas chromatographs is given in Appendix 6, Volume VI. This gas chromatrograph actually consists of four columns which are identified in the block diagram, Figure 5-20, as are the constituents being detected by each column. The estimated thermal program and power requirements are shown in Figure 5-21. The requirement for the low column temperature arises from the difficulty of separating argon and oxygen as well as NO and CO at higher temperatures. These two columns are housed in a single cooling jacket and oven, since their thermal programs are the same. No temperature program is required for the remaining two columns so that they can be housed together in a single temperature control oven. A schematic diagram showing more of the detail elements of a single column is shown in Figure 5-22. An RF glow discharge detector is indicated on the diagram. A neon glow discharge detector could be used but requires a lower outlet pressure and has somewhat less sensitivity. The RF discharge detector can detect concentrations of 10^{-8} mole as compared to 10^{-6} for the neon glow discharge detector.

This gas chromatograph also uses a mass spectrometer as a detector. The effluent from the gas chromatograph is sampled when a peak is detected by the glow discharge detector and diverted to the mass spectrometer sample inlet chamber. The oven configuration is shown in Figure 5-23. This oven configuration is also used for the remaining gas chromatograph to be described later. The external configuration for this gas chromatograph is shown in Figure 5-24.

p. Gas Chromatograph No. 2. This gas chromatograph is used in Experiment No. 18 to detect amino acids by pyrolyzing a soil sample and analyzing the evolved gases. This instrument differs from the other gas chromatographs in that it utilizes a solid soil sample and does not use the mass spectrometer as a detector in conjunction with the argon β-ionization detector. The column packing for this column is tentatively defined as 15-percent Apiezon L, 4.5-percent carbowax 20 M, and 3-percent phosphoric acid on a chromasorb support. The block diagram in Figure 5-25 shows the elements of this system. The external configuration and size are shown in Figure 5-26. A typical thermal and power profile for the remaining gas chromatographs are shown in Figure 5-27. See Appendix 6, Volume VI, for additional details on this instrument.

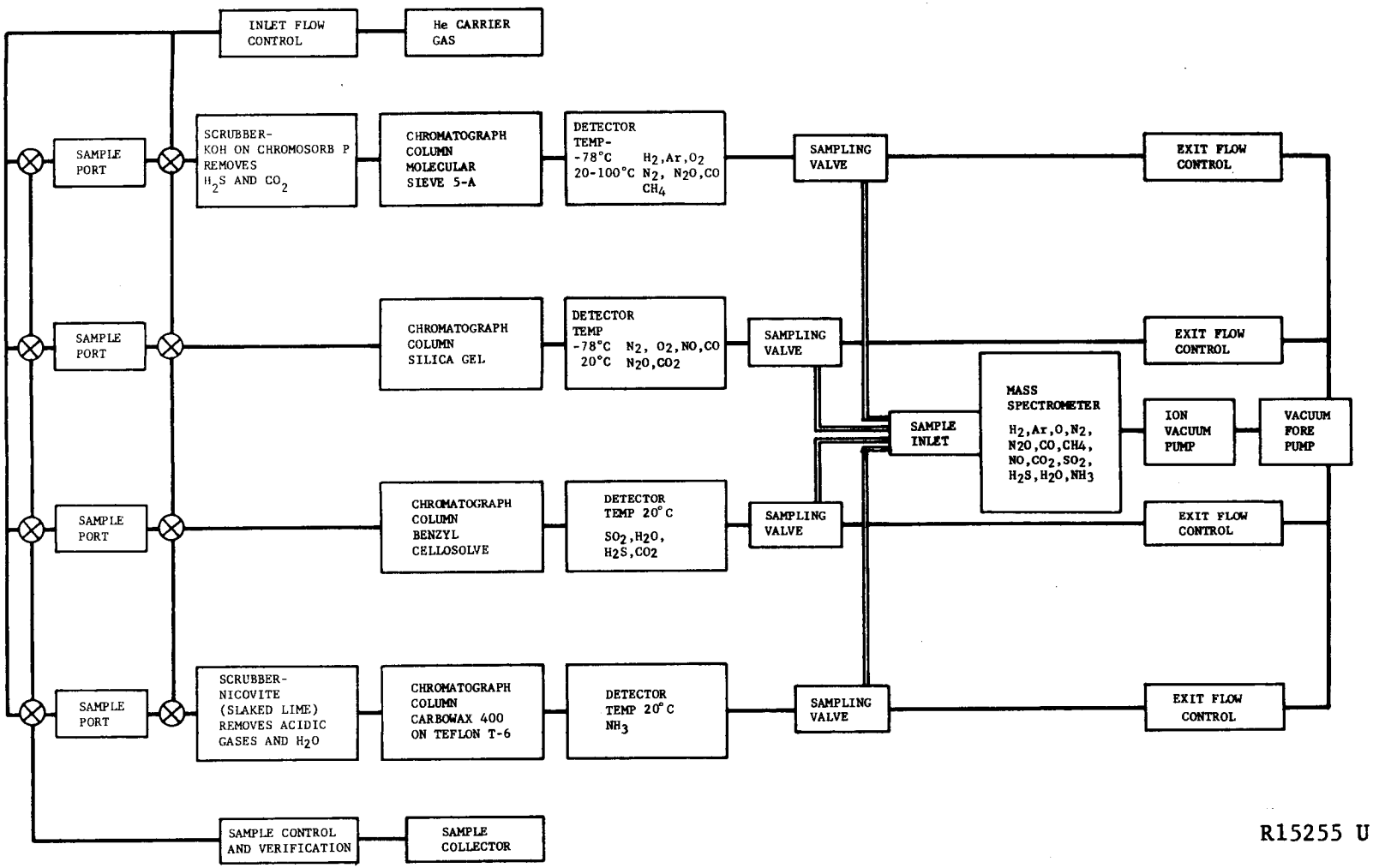

FIGURE 5-20. BLOCK DIAGRAM - GAS CHROMATOGRAPH NO. 1 ANALYSIS SYSTEM

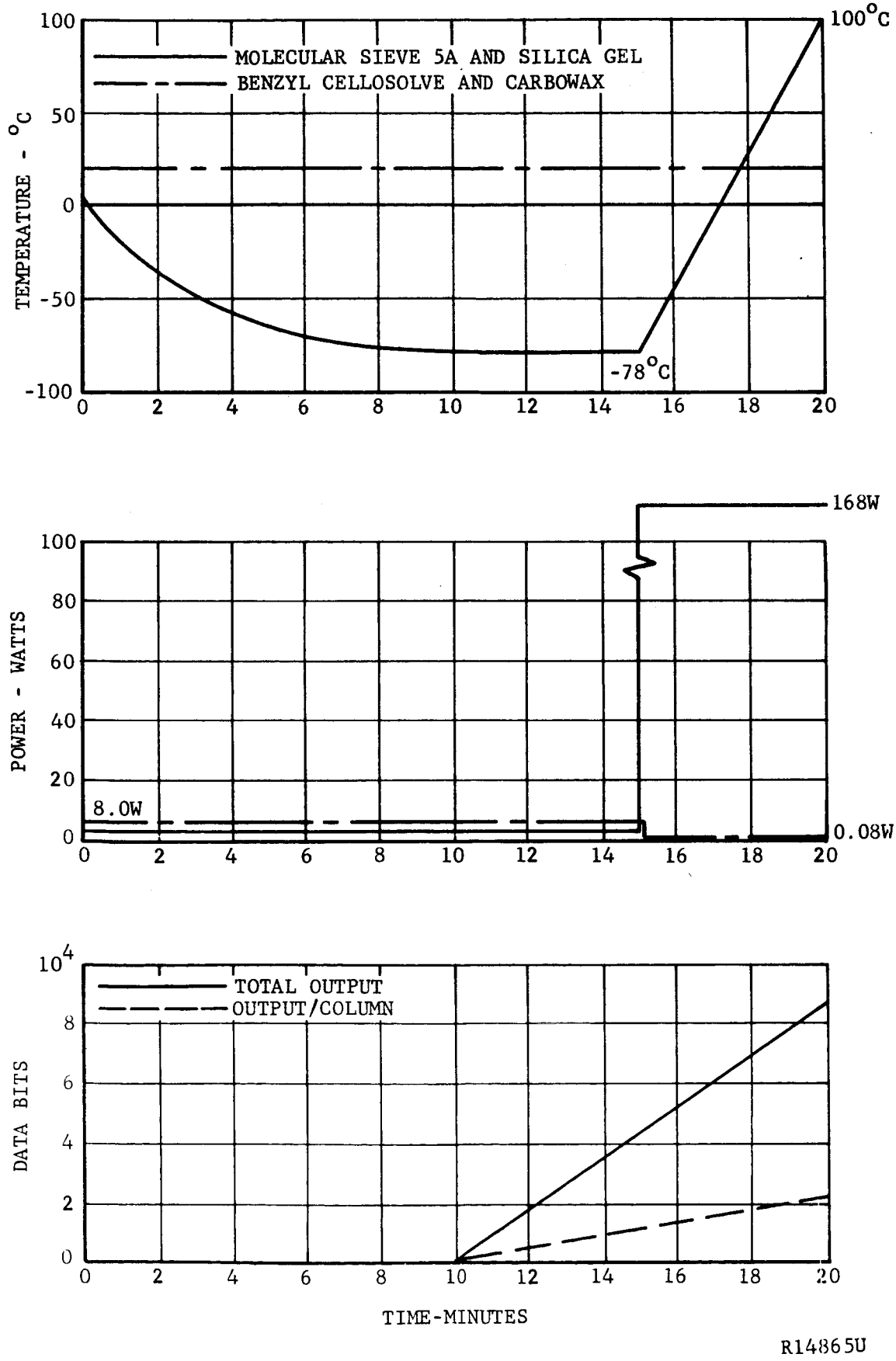

FIGURE 5-21. GAS CHROMATOGRAPH NO. 1 CHARACTERISTICS

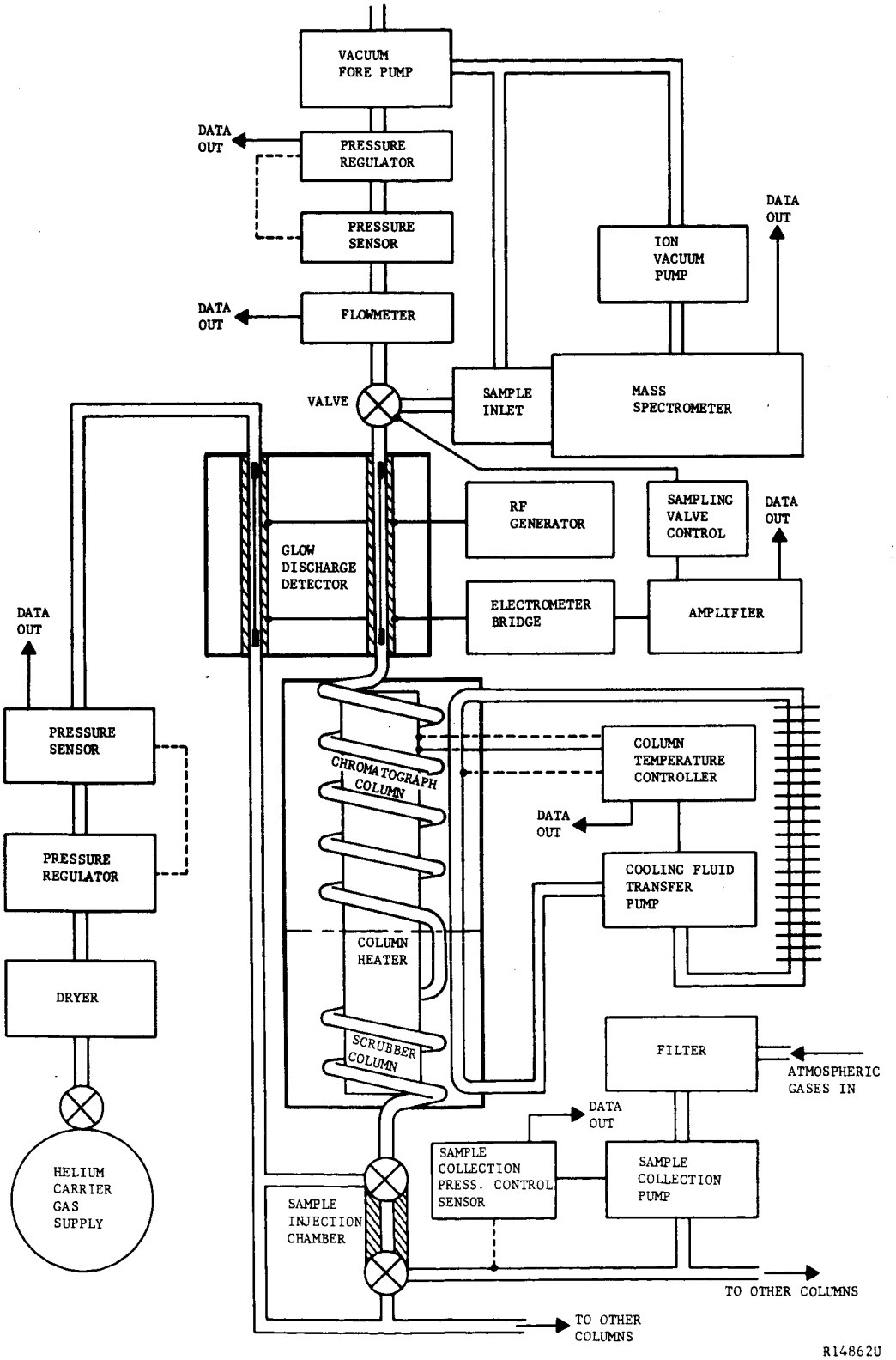

FIGURE 5-22. SCHEMATIC - ATMOSPHERIC ANALYSIS GAS CHROMATOGRAPH

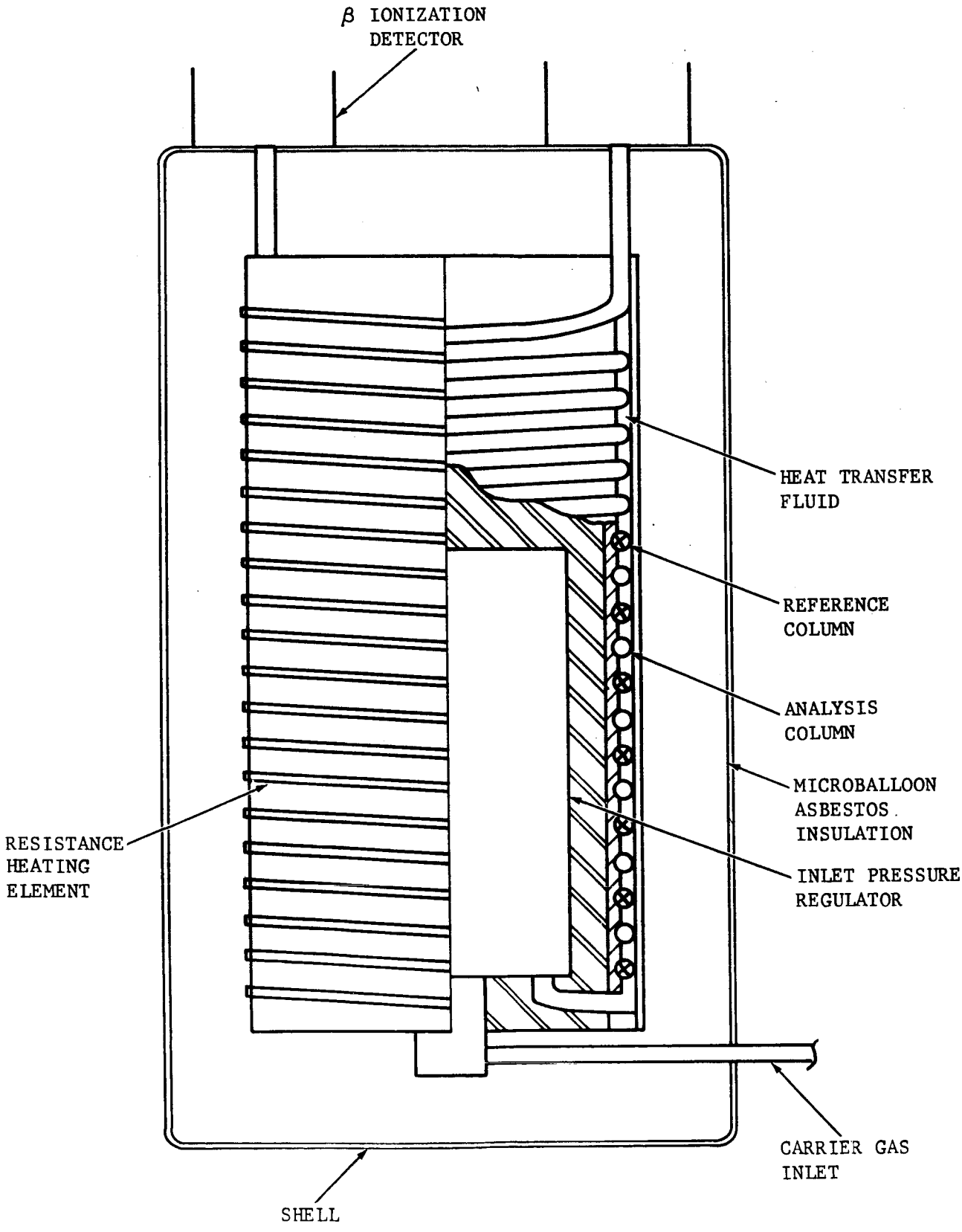

FIGURE 5-23. GAS CHROMATOGRAPH INTERNAL CONFIGURATION

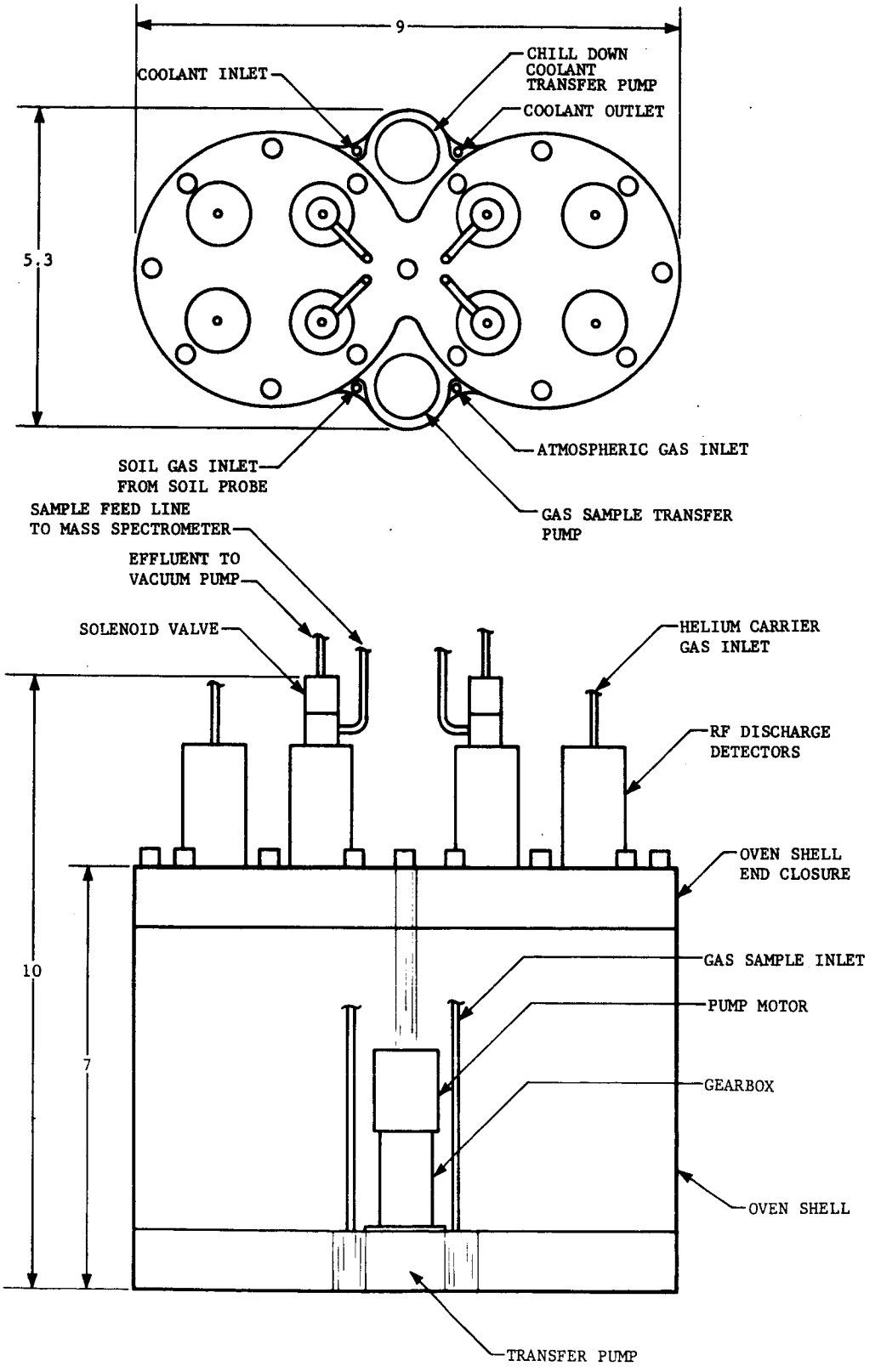

FIGURE 5-24. CONFIGURATIONAL ENVELOPE GAS CHROMATOGRAPH NO. 1

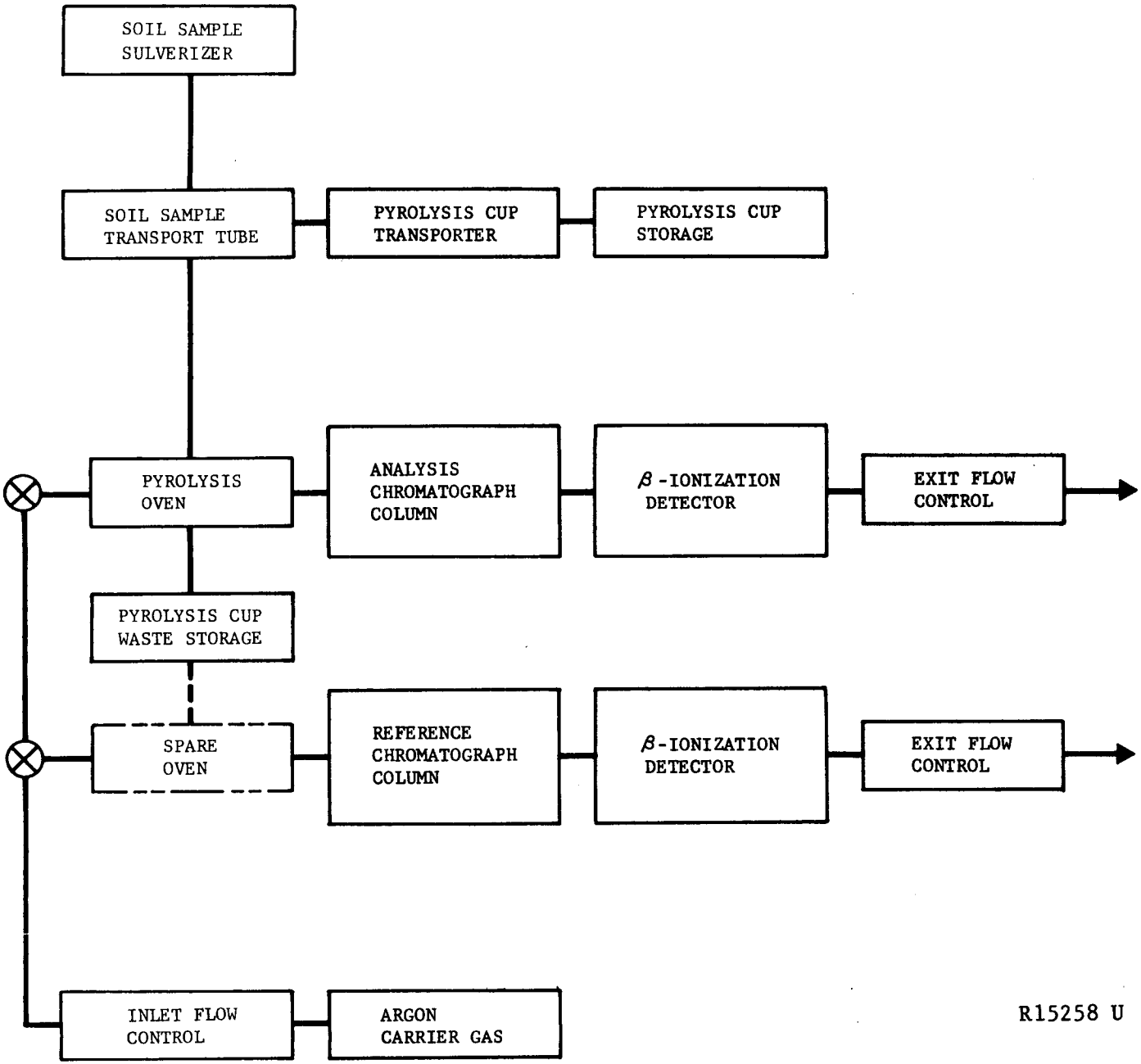

FIGURE 5-25. BLOCK DIAGRAM - GAS CHROMATOGRAPH NO. 2 ANALYSIS SYSTEM

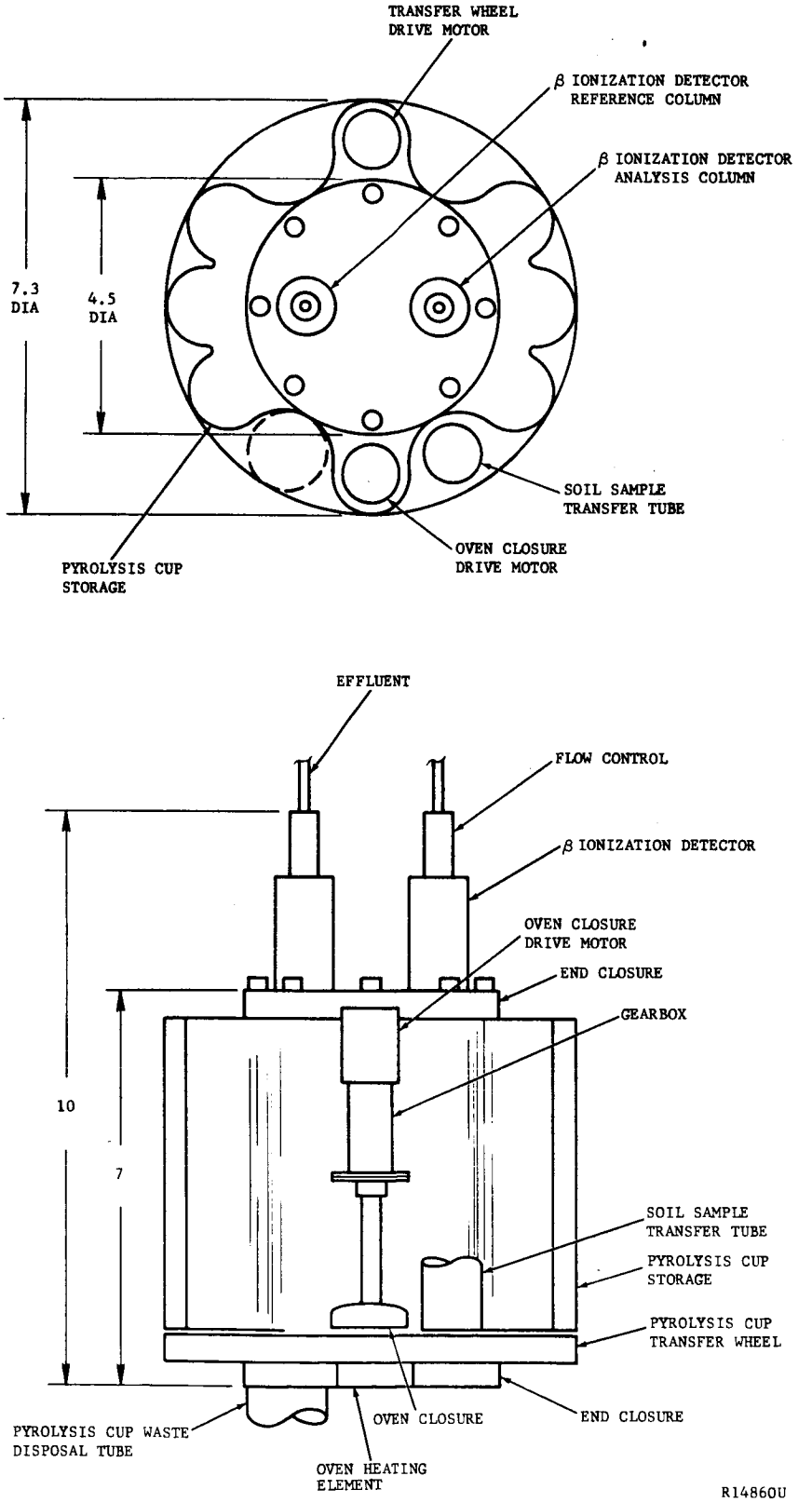

FIGURE 5-26. CONFIGURATIONAL ENVELOPE GAS CHROMATOGRAPH NO. 2

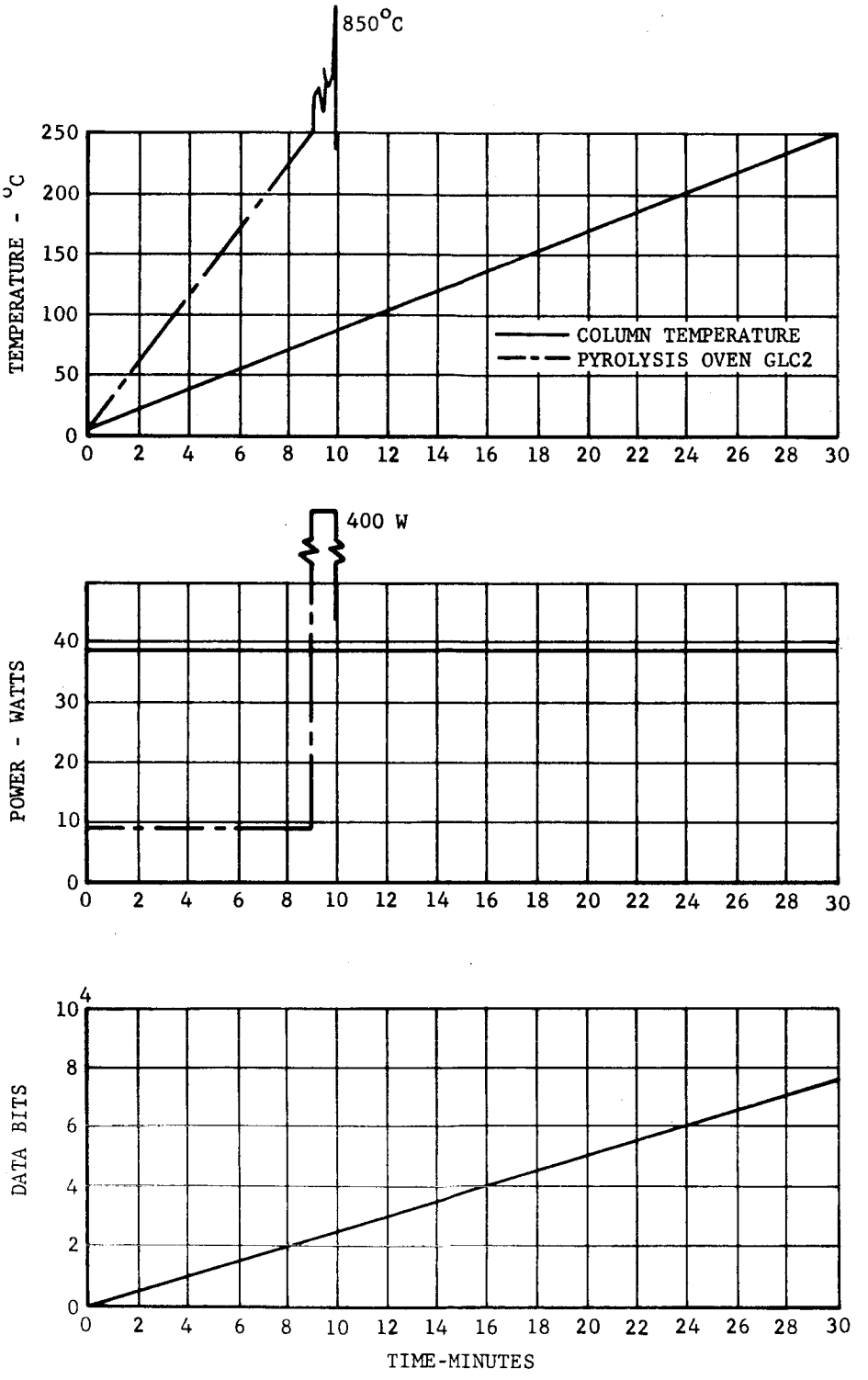

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FIGURE 5-27. GAS CHROMATOGRAPH NO. 2 THROUGH NO. 5 CHARACTERISTICS

q. Gas Chromatographs Nos. 3, 4, and 5. These gas chromatographs are identical from an engineering and configurational viewpoint. The tentative column packings are listed in Table 5-III for these gas chromatographs as well as the experiment in which it is used. The block diagram in Figure 5-28 shows the elements of the analysis system. It is seen that the mass spectrometer is used in conjunction with the argon β detector. It should be noted here that gas chromatographs Nos. 2 through 5 use a dual column. The same packing is used in each column, one of which is used to perform the analysis and the other is a reference. The purpose in this dual column configuration is to reduce base line drift by reading the differential output of the detectors. Drift can be caused by column bleeding, vaporization, and polymerization of the liquid phase. The extra column also provides redundancy in the event that the analysis column fails. It can be used to perform the same analysis at some reduction in data reliability.

The external configuration and size for gas chromatographs Nos. 3, 4, and 5 are shown in Figure 5-29.

TABLE 5-III

GAS CHROMATOGRAPHS COLUMN PACKINGS

Gas Chromatograph	Packing	Experiment
No. 3	SE-30 Silicone polymer on a Chromosorb W support	22
No. 4	Acid washed glass bead support coated with 0.25-percent Carbowax, and 0.4-percent isophthalic acid solution.	23
No. 5	15-percent Apiezon L, 4.5-percent Carbowax 20 M, and 3-percent phosphoric acid on a Chromasorb support.	19 and 27

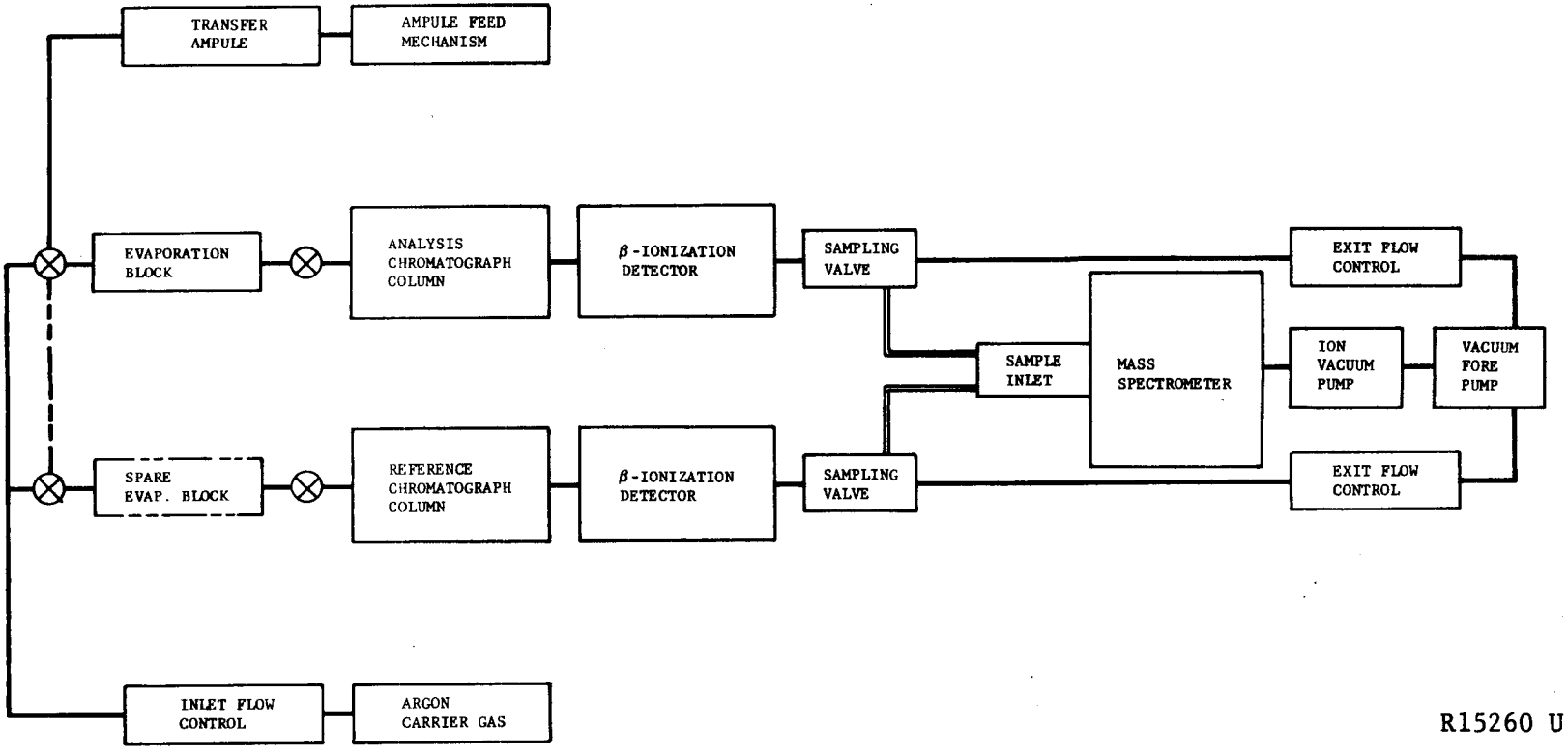


FIGURE 5-28. BLOCK DIAGRAM - GAS CHROMATOGRAPH NO. 3, NO. 4, AND NO. 5

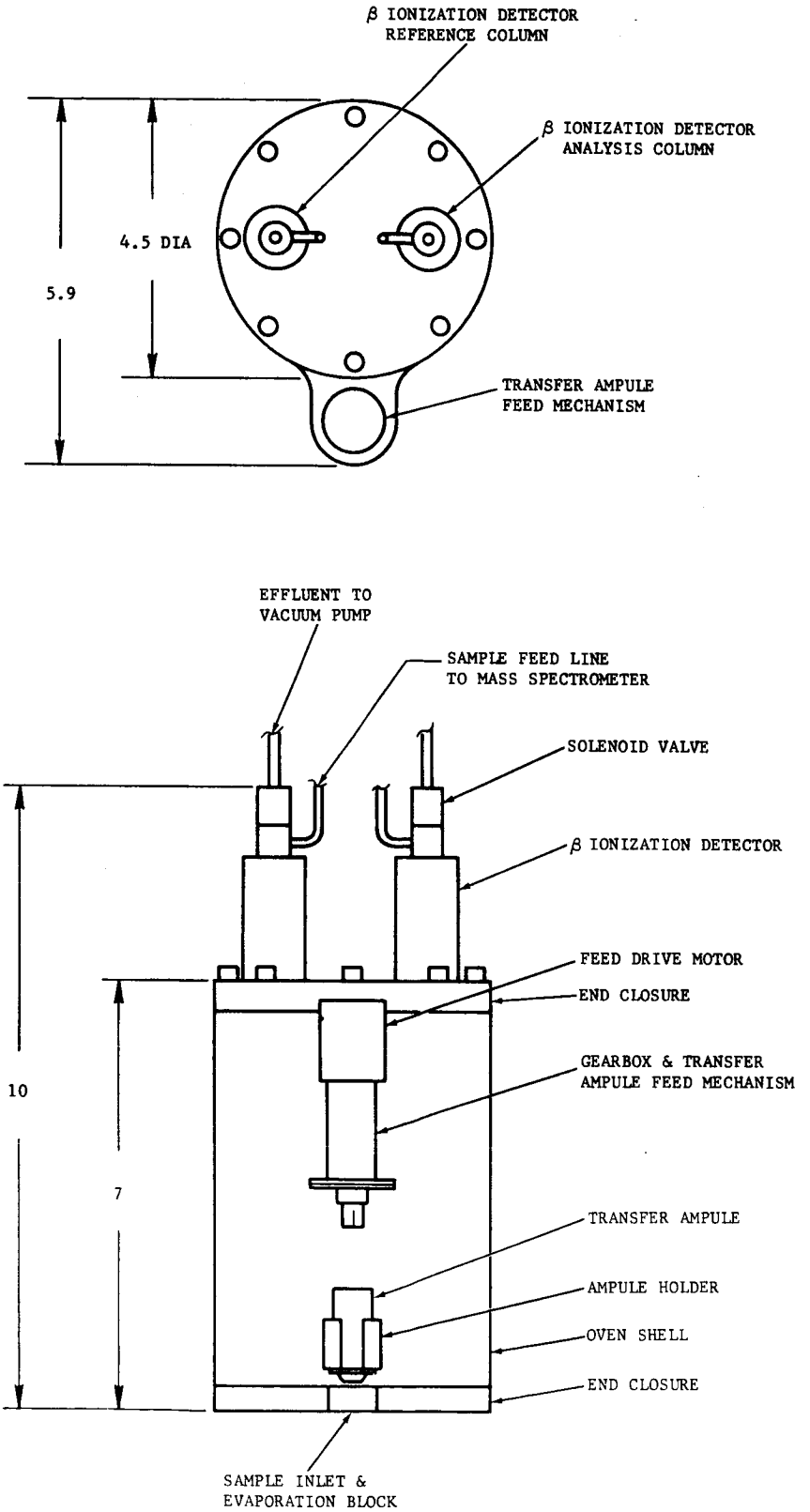


FIGURE 5-29. CONFIGURATIONAL ENVELOPE GAS CHROMATOGRAPH NO. 3, NO. 4, AND NO. 5

r. Spectral Analyzer. The ultraviolet and visible range spectrophotometer, as well as the fluorimeter and polarimeter, have been combined in a single unit as shown schematically in Figure 5-30. In order to cover the complete frequency range desired, i.e., 250 mμ to 2 μ, fused silica optical elements and front surfaces mirrors are used. By stepping the appropriate optical elements in or out of the light path, the instrument can be used in three modes as a dual beam optical null spectrophotometer, as a fluorimeter, and as a polarimeter. Multiple detectors mounted on a turret will provide the versatility and dynamic range required to satisfy all three modes of operation. Photomultiplier tubes and solid-state detectors are used to provide this flexibility and reliability. A Xenon lamp source is the primary light source since it provides a useful range from 200 mμ to 3.5 μ. A tungsten lamp source will provide backup for the primary source to allow low power operation if required.

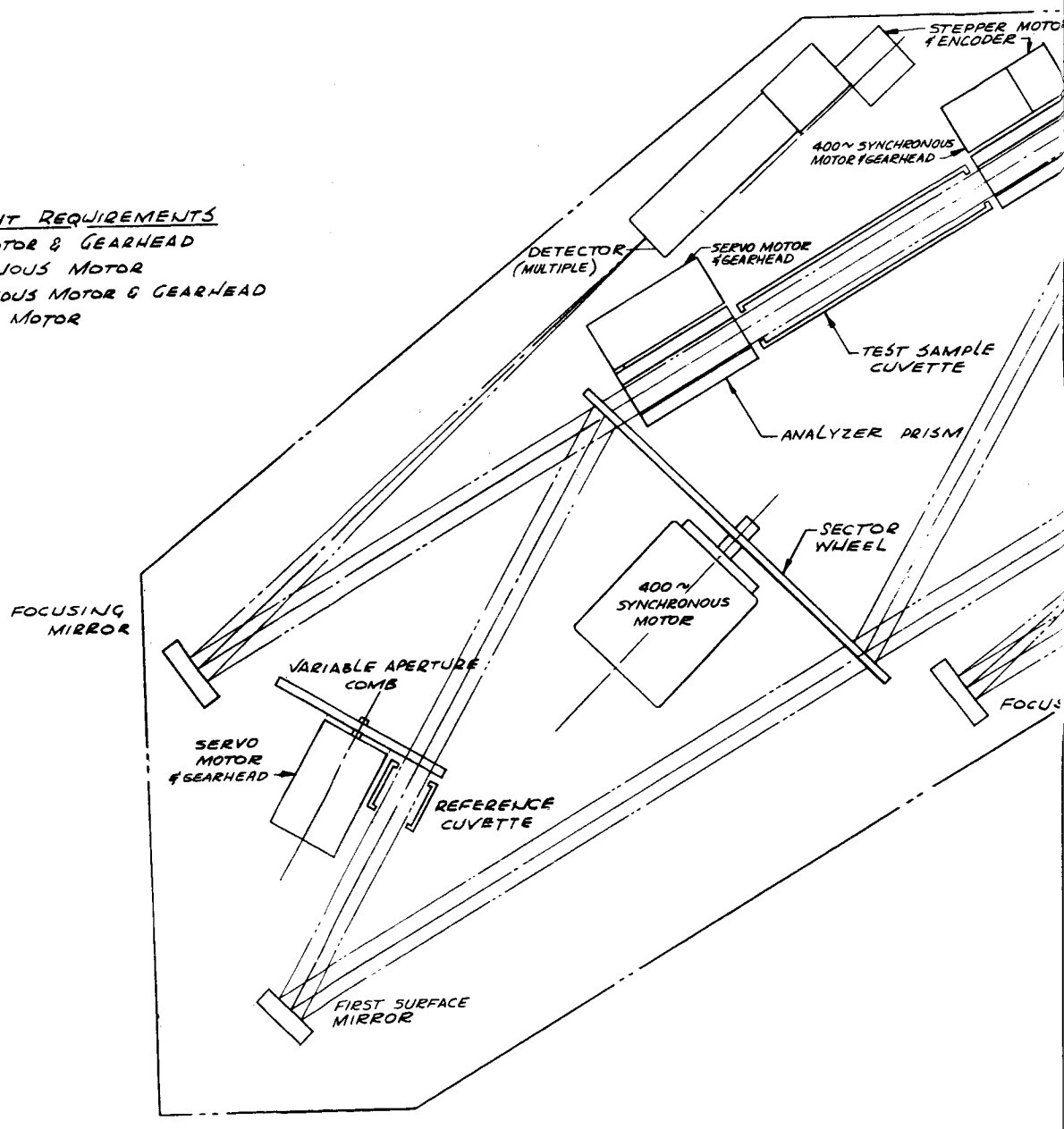
To operate as a spectrophotometer, the polarizer and analyzer prisms are stepped out of the beam as is the flat mirror used during fluorimetry. The operation is the same as laboratory spectrophotometers in this mode. To perform fluorimetric analyses, a flat mirror is stepped into the light path of the source between the collimating mirror and the prism monochromator. An interference filter is stepped into position between the source and the sample to irradiate it at frequencies of 350, 405, and 445 mμ, respectively, for experiments 16, 20, and 21. The light emitted by the fluorescing sample is then scanned through the visible spectrum from 500 to 700 mμ. To use the instrument as a polarimeter, the fluorimeter mirror is stepped out of position, and the polarizer and analyzer prisms are stepped into position. In this mode of operation, a scan is first made with no sample in the test cuvette and is then followed with a scan through the test sample. Since small rotation angles of the plane of polarization are to be determined to an accuracy of 0.001 degree, a static determination of this rotation does not appear to lend itself to automation.

The intensity of light transmitted through a polarizer and analyzer crossed at some angle, θ, varies as $I = I_o \cos^2 \theta$. This produces a curve with broad maximums and minimums as shown in Figure 5-31. It is suggested that a dynamic system using a rotating analyzer will be more suitable for automation. Dynamic systems using an intense oscillating magnetic field to rotate the plane of polarization of a Faraday cell have been built and are in use; however, a solid state system is more desirable for the ABL. The output of the detector using a rotating analyzer is given by

$$\frac{dI}{dt} = I_o \sin 2\theta \frac{d\theta}{dt}$$

COMPONENT REQUIREMENTS

5 SERVO MOTOR & GEARHEAD
1 SYNCHRONOUS MOTOR
1 SYNCHRONOUS MOTOR & GEARHEAD
5 STEPPER MOTOR
9 MIRRORS
3 PRISMS
2 LENSES



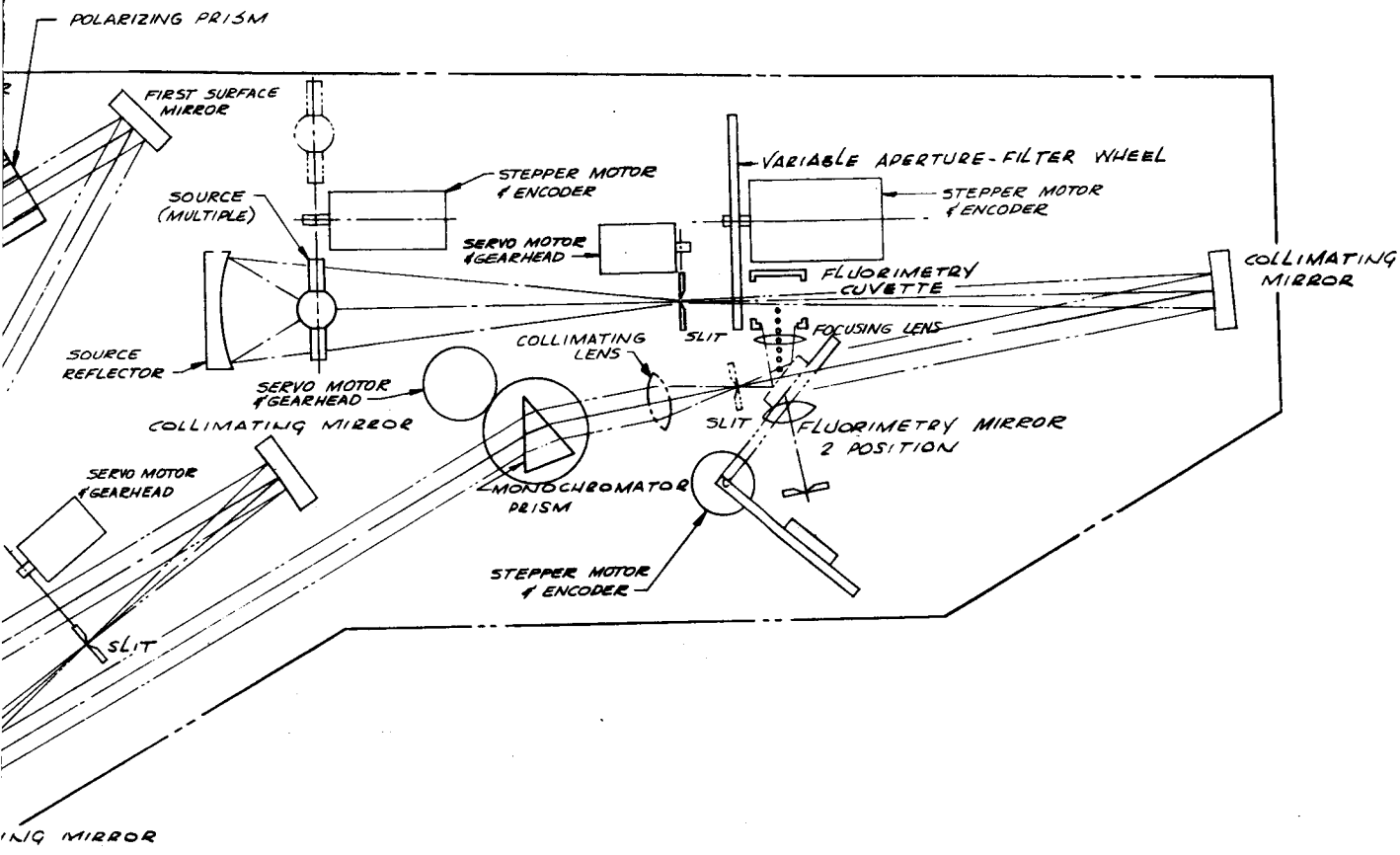


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FIGURE 5-30. SPECTRAL ANALYZER

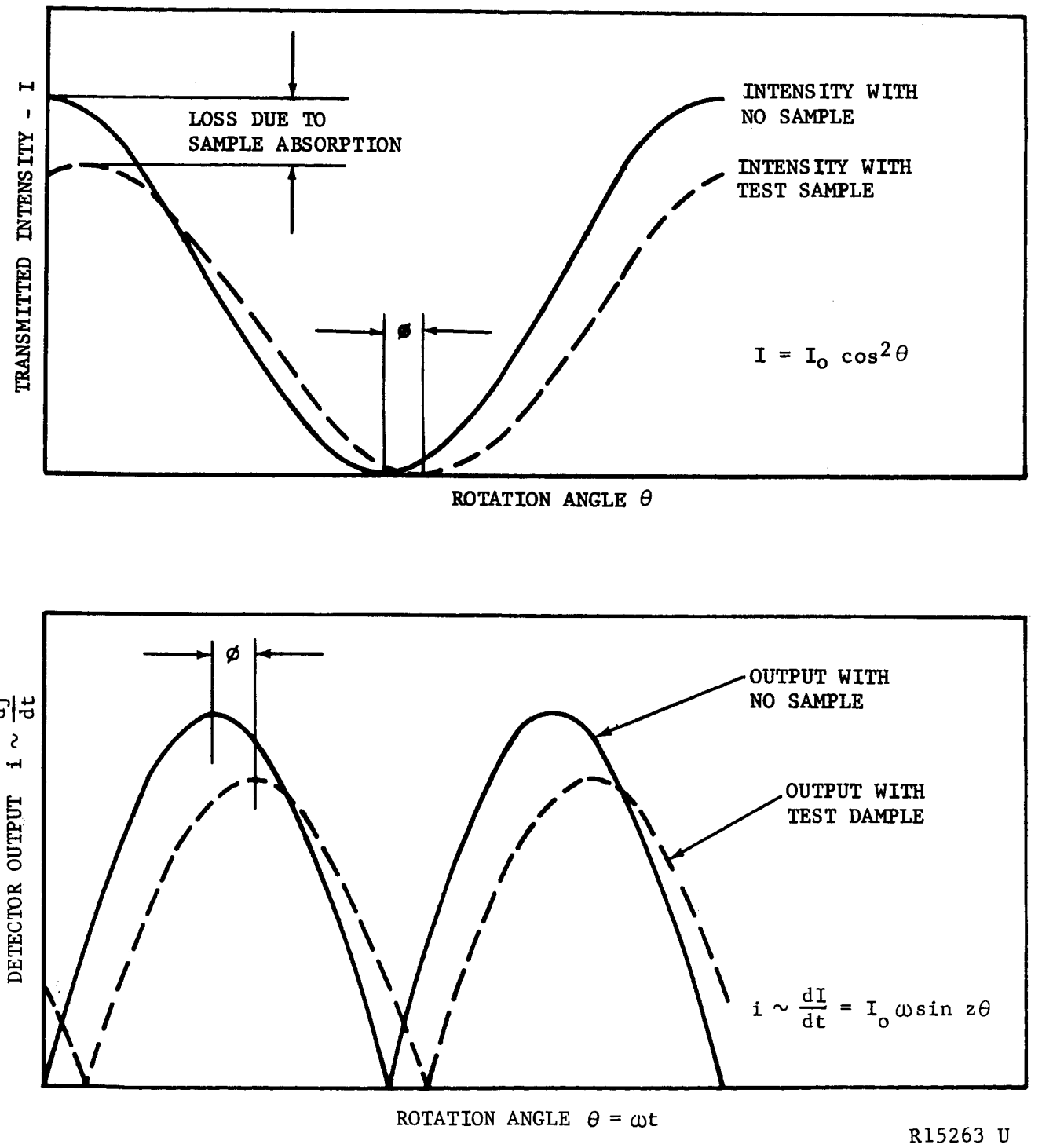

FIGURE 5-31. CHARACTERISTICS OF ROTATING POLARIMETER INSTRUMENT

Thus, an alternating output is achieved with the frequency dependent on the speed of rotation. This output waveform can then be fed to a differential analyzer circuit which will produce sharp peaks. By comparing the position of this peak without a sample in place and with a sample in place, the optical rotation angle, ϕ, can be determined. Simultaneous comparison of the peak positions can be made if the test sample occupies only half the beam and two detectors are used to sense the light intensity which might be more desirable from an electronic viewpoint. It should be noted that with this method neither the maximum nor minimum intensities of transmitted light is being used but rather the maximum rate of change of light intensity with the relative polarization angle θ. Absorbance of the test sample can be determined from the change in the absolute magnitude or height of the peaks.

A preliminary functional specification for the spectral analyzer operation in each of its three modes has been prepared as follows:

(1) Ultraviolet Spectrophotometer Mode

Wavelength Region

250 mμ to 700 mμ

Resolution

To the nearest 1 mμ

Range of Absorbancy*

0 to 2

Accuracy

0.1 absorbancy unit

(2) Fluorimeter Mode

Excitation Wavelengths

350, 405, and 445 mμ

(uses interference filters)

---

*Absorbance is defined as

$$\log \frac{I_o}{I}$$

Scanning Wavelength Region

500 to 700 mμ

Resolution

To nearest 1 mμ

Range of Emission Intensity

Two decades of relative emission intensity. In addition, the source (excitation) intensity should be variable over two decades by slit width variation.

(3) Polarimeter Mode

Wavelength Region

Incident polarized light should be in the wavelength band from 270 to 290 mμ . Also, as a backup, another frequency such as the sodium D line (590 mμ) is required.

Range of Angular Rotation

±360 degree desired; ±30 degree adequate.

Accuracy of Rotation Measurement

±0.001 degree

Range of Light Intensity Sensitivity

Two decades.

s. Infrared Spectrophotometer. Infrared absorption spectroscopy can be applied to identify small, characteristic groups of atoms (functional groups) by determining vibrational frequencies of the bonds of the functional groups. The vibrational absorptions of interest occur in the wavelength region from 2μ to 14μ and longer (or in terms of wave numbers from 5000 cm^{-1} to 700 cm^{-1}). Thus, the infrared spectrophotometer for ABL must operate from 2μ to 14μ. An optical system similar to that used by Beckman Instruments in their IR-5A infrared spectrometer is used. In order to avoid the necessity of using a NaCl prism which lacks strength, is susceptible to damage by moisture, and is probably not satisfactory for dry heat sterilization, a synthetic sapphire prism will be used. This material has

already been discussed in connection with the infrared scanning system associated with the macroimaging scan and will provide the desired range for the instrument. A schematic diagram for this instrument is shown in Figure 5-32.

Samples will be in the form of liquids or solutions. Therefore, the optical path through the sample will be between 0.1 and 1 mm. These samples are prepared prior to infrared analysis by the chemical processing equipment using specified procedures.

Resolution of about 5 cm^{-1} should be achieved without great difficulty. Optical mounting and alignment design must insure that degradation because of the thermal stresses of sterilization and accelerations of landing is not incurred.

Absorbancy is defined as log I_o/I, where I_o is the incident intensity of infrared radiation and I is the intensity of light emerging from the sample cell. Commercial instruments operate over a range of absorbancy from 0 to 2. For terrestrial laboratory application this is quite adequate. If the absorption of a sample is too great, a human technician either uses a smaller sample cell thickness or dilutes the sample. However, for remote operation, a wider range of absorbancy may be desirable to simplify the sample preparation and conditioning operations. An absorbancy range from 0 to 2 is adequate, but a greater range is desirable if it can be achieved. The accuracy on the absorbancy at a given wavelength should be 0.1 absorbancy unit.

It is likely that the concentration of organic materials in Martian surface material soluble in carbon tetrachloride or similar solvents will be very small. The instrument should then operate in two modes. First, the sample would be analyzed using a broad absorbancy range (0 to 2 or greater). If no significant absorption is detected or if only one or two major absorption peaks are seen, the instrument would switch to a more sensitive range, say from 0 to 0.1, in order to pick up absorption bands of any small amounts of organic material which are present.

t. Mass Spectrometer. This instrument is used as another detector for the gas chromatograph to provide additional verification of the data. Used in this manner, the gas chromatograph supplies a sample which is rendered less complex by the separation achieved in the chromatograph column. This will provide more reliable and simpler interpretation of the data for both instruments. The mass spectrometer can also be used independently to provide still another set of data for verification and interpretation. A double focusing mass spectrometer utilizing magnetic scanning was selected as satisfying the requirements for the ABL in terms of resolution, control and dynamic range. In making this selection, two other types of mass spectrometers were considered. The time of flight instrument is

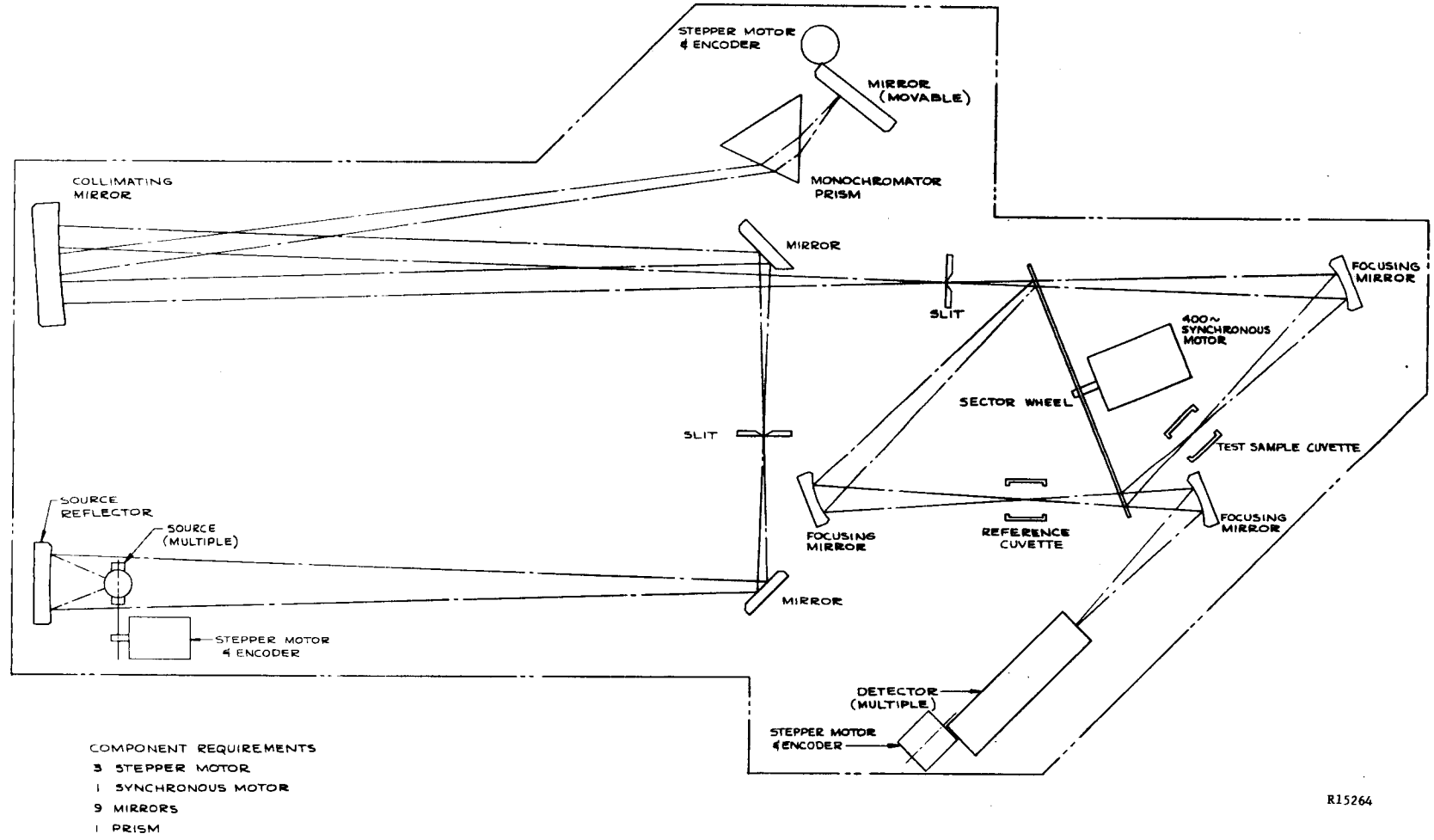

FIGURE 5-32. IR SPECTROPHOTOMETER - OPTICAL SCHEMATIC

desirable because it requires no magnetic field and has a very rapid scan. While this instrument is theoretically capable of good resolution up to AMU of 5000, the practical limit is approximately 140. Another type which appears promising is the quadruple mass spectrometer. This instrument is capable of high resolution and also requires no magnetic field; however, for a given length to deflection radius ratio, the RF excitation power is proportional to the fifth power of the product of deflection radius and RF frequency. Thus, either high power or long length is required. Both the preceding instruments should be potentially lighter because no magnet is required.

The double focusing mass spectrometer indicated schematically in Figure 5-33 is based partly on a design developed by Consolidated Systems Corporation, Monrovia, California. The basic deflection angles and radii were maintained. These are 60 degree deflection and 2.5-centimeter radius for the electrostatic sector and 90 degree deflection and 5-centimeter radius for the magnetic sector. Since a magnetic sweep will allow a range of AMU from 2 to 400 to be scanned, changing the voltage of the electrostatic sector limits the sweep to a range of 10 to 1. Thus, in order to achieve a full range of scan, the magnetic sweep was selected even though precise control of the field strength is more difficult. A permanent magnet with a field strength of about 3500 lines/cm^2 was used on Consolidated Systems Instrument. This is replaced with an electromagnet, so that the field strength can be varied. The variation of mass to charge ratio is given by the expression

$$\frac{m}{e} = \frac{H^2 r^3}{2V}$$

Assuming the field strength of 3500 lines/cm^2 to focus an AMU of 32 at a radius of 5 centimeters, the upper and lower limits of required field strength for AMU of 400 and 2 were determined. This range is shown in Figure 5-34. It is seen that saturation of the core material is being approached for sheet steel; however, the feasibility of scanning this range magnetically is established. If need be, a combination of magnetic sweep and voltage sweep can be used.

A resolution of one AMU is required for compounds which contain a considerable number of carbon and hydrogen atoms. Since resolution is partially dependent on the collector slit width, it is desirable to vary this. The method of accomplishing this indicated in the schematic of Figure 5-33, is to use two fixed slits of different width. When the narrower slit is shorted to the collector, it also acts as a collector, and the larger slit is effective. When it is switched to the larger slit, it then acts as the effective slit. The external configuration of this mass spectrometer is shown in Figure 5-35. The configuration as shown must be supported with a vacuum system consisting of a fore pump and ion pump. Vacuums of the

A - REPELLER PLATE
B - ELECTRON BEAM
C - ACCELERATOR PLATE
D - ACCELERATOR PLATE
E - ACCELERATOR PLATE & SOURCE SLIT
F - 1ST COLLECTOR SLIT
G - 2ND COLLECTOR SLIT
H - COLLECTOR
I - SLIT APERTURE CONTROL SWITCH

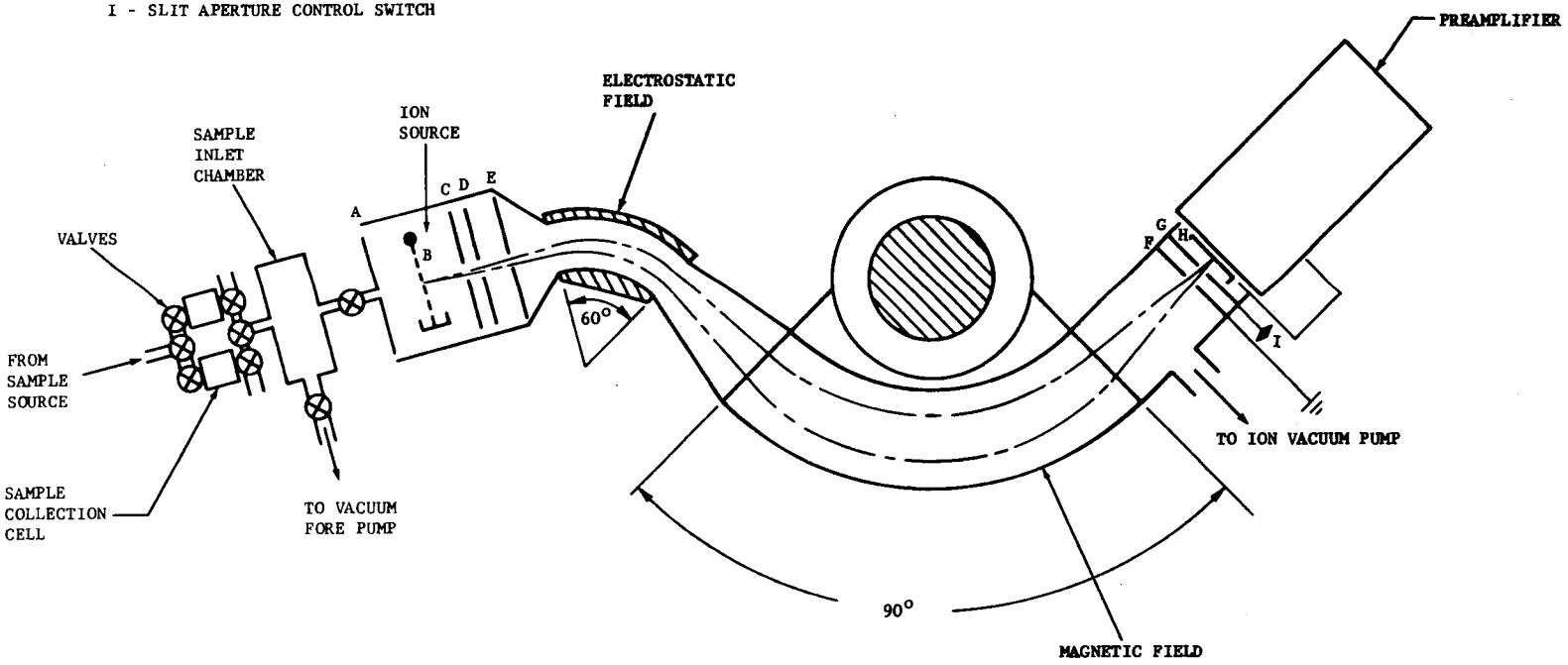

FIGURE 5-33. SCHEMATIC - DOUBLE FOCUSING MASS SPECTROMETER

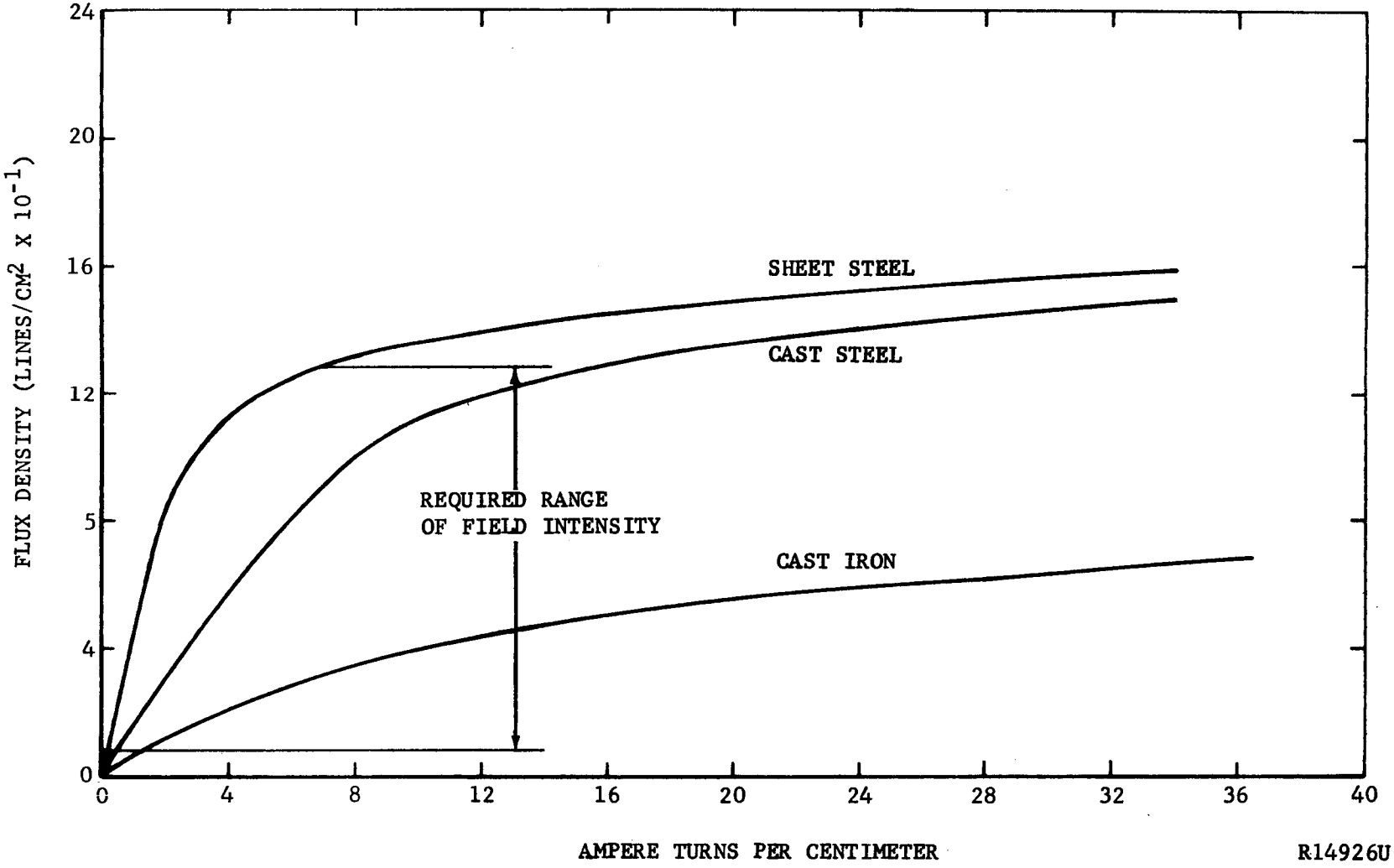

FIGURE 5-34. MAGNETIZATION CURVES FOR TYPICAL MATERIALS

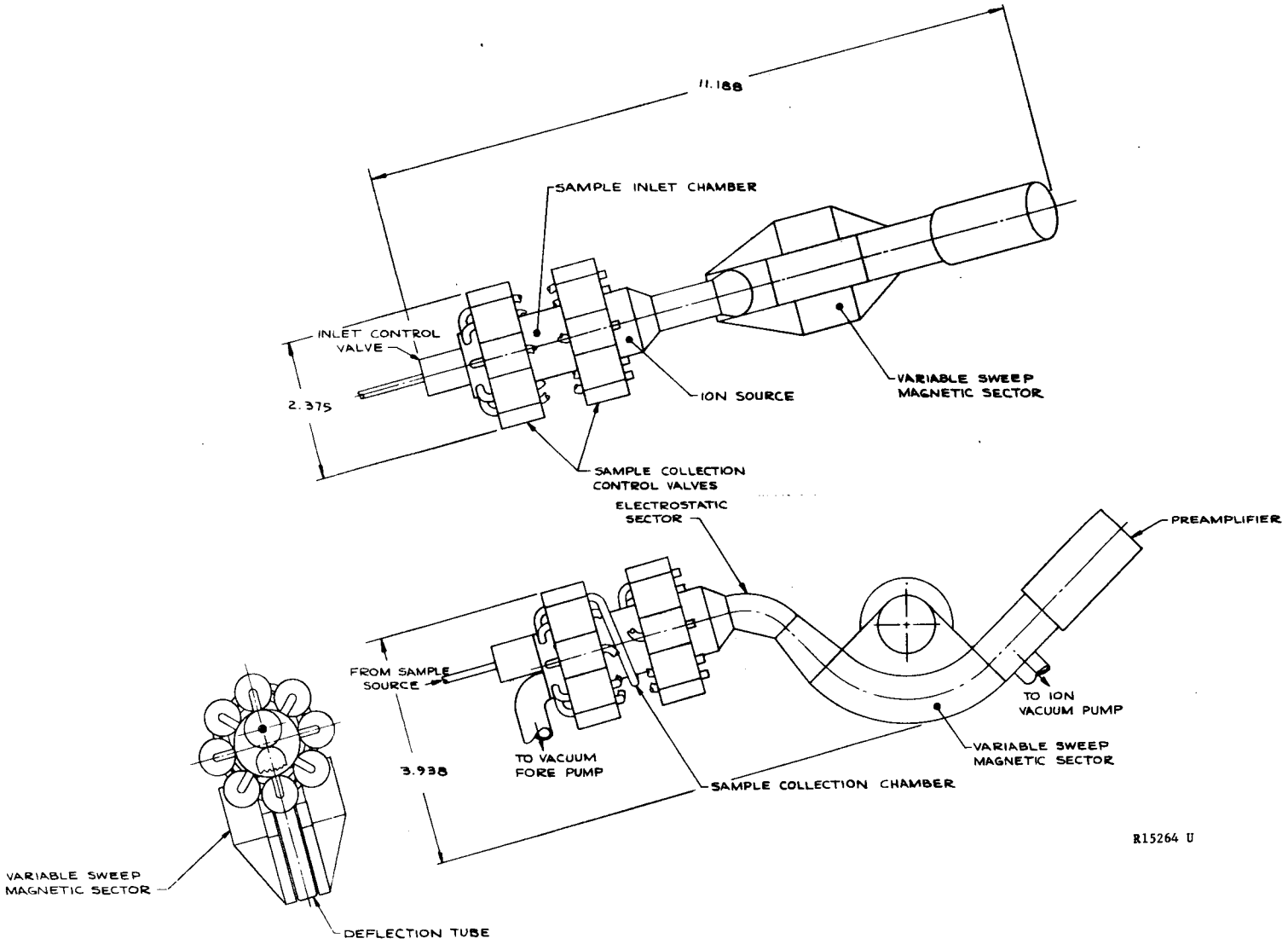

FIGURE 5-35. CONFIGURATION OF DOUBLE FOCUSING MASS SPECTROMETER

following magnitudes are typical. The deflection path and collector require 10^{-8} mm Hg. The sample in the ion source should be at 10^{-5} mm Hg and in the inlet chamber in the order of 10^{-2} mm Hg. Other supporting functions are data processing and conditioning equipment as well as control. The sample inlet system is designed so that peaks detected by the gas chromatograph can be stored in sample collection chambers up to a maximum of eight. This is necessary, since the scan rate for the mass spectrometer is in the order of 1 to 5 minutes. In some cases, peaks will occur this rapidly which will not allow the mass spectrometer sufficient time to scan the sample, purge the sample inlet chamber, and pump it down to the requisite pressure necessary to introduce the next sample.

u. Weight Scale. A weight scale with a dynamic range of 10^4 was desired so that a single scale can be used to measure both large and small samples. In order to ensure reliable operation and maintain simplicity in the automatic operation of such a scale, the criterion was established to eliminate knife edges or weight balances. A null-type torsion balance was selected as most promising and is shown in Figure 5-36. The detailed analyses supporting this instrument are given in Appendix 6 of Volume VI. The principle of operation is that a torsion bar is used to balance the torque produced by loading a beam supported with wires inclined out of the plane of the applied force. An optical sensing system and servo drive maintains the weight pan at an index position by increasing the torsion in the bar until a null is achieved. With this system, changes in geometry are avoided and as long as the proportional limit of the torsion bar material is not exceeded, a linear response is obtained.

v. Soil Probe. This instrument is essentially a soil probe which mounts water vapor detectors and resistance thermometers at 5-centimeter intervals. The probe is deployed into the surface of Mars pyrotechnically. Depth sensors are mounted at each 5-centimeter interval to determine the depth of penetration. The first 5 centimeters of the probe is perforated and connected through capillary tubing to the atmospheric and soil gas analysis gas chromatograph. The probe will thus also function as a collector for gases in the soil. The general configuration of such a probe is shown in Figure 5-37.

5.3.3 INSTRUMENT DEVELOPMENT STATUS

In generating the definition of instruments required by the experiment complement, primary emphasis has been placed on determining the appropriate instrument and its operational modes. Miniaturization has not been pursued in every case. A summary of the status of these instruments is given in

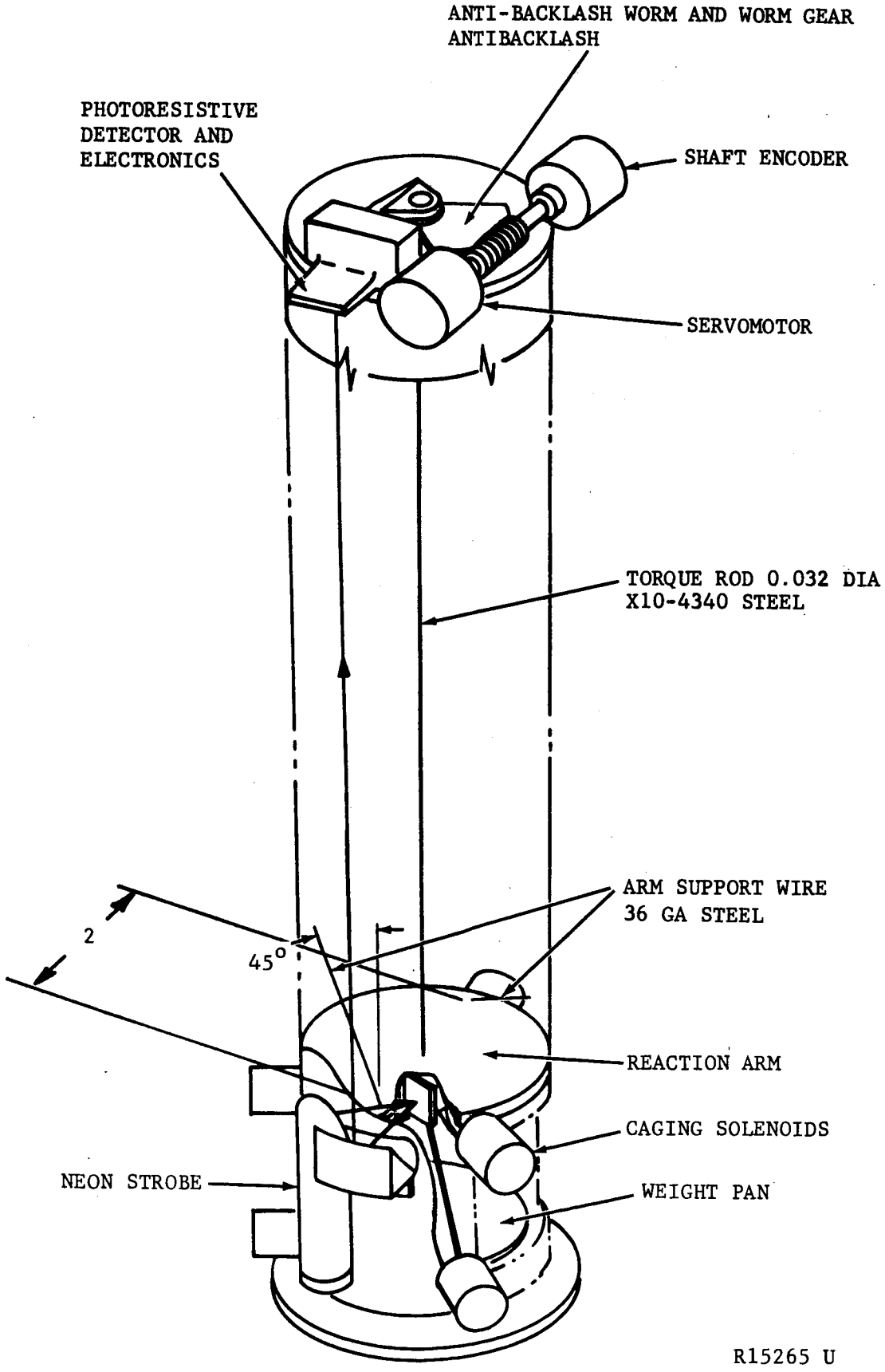

FIGURE 5-36. SCALE CONCEPT

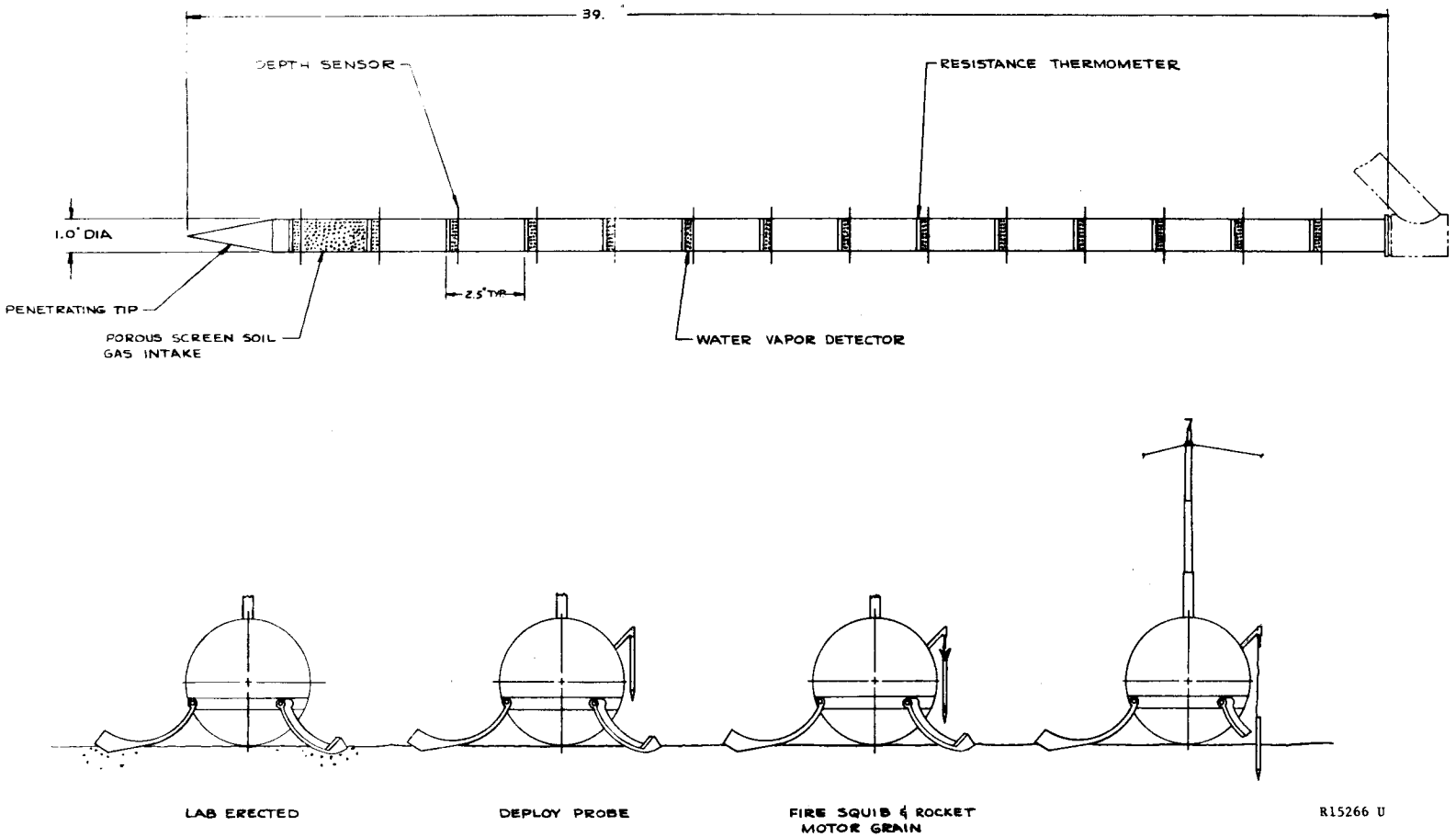

FIGURE 5-37. SOIL PROBE

Table 5.IV. The developmental status of the instruments is indicated at four levels. The definition of these levels is given as follows:

- Qualified is that level in which space qualified components are currently in existence.
- Design qualification is that level in which a prototype design is in existence, but has not yet been qualified for space flight.
- Design development is that level in which breadboards have established feasibility or laboratory equipment exists from which prototype flight equipment is designed and tested.
- Conceptual development is that level for which complete feasibility has not been established in terms of space applications and involves the fabrication of breadboard models to prove feasibility.

The level of development status is indicated for each instrument under the appropriate column. Where two levels are indicated for an instrument, the implication is that the highest state of development and qualification exists for this instrument in some current application but that the next lower level of development is the status for application in an ABL payload. The remarks column indicates the company or agency and, where applicable, the contract number for instruments or sensors which are under development for space applications which may be applicable to an Automated Biological Laboratory.

TABLE 5.IV

INSTRUMENT DEVELOPMENT STATUS

Instruments	Qualified	Design Qualification	Design Development	Conceptual Development	Remarks
Thermometers	X				
Atmospheric Sensors		X	X		
Water Vapor Detector		X			Parametrics, Waltham, Mass JPL 950684
Microphone with Resonator	X				JPL (Mariner)
Omnidirectional Microphone		X			
β and γ Ray Counter			X		
Core Hole Sonde	X	X			Texaco Experiment, Inc. NAS7-100 and JPL 950155
Soil Mechanics Apparatus			X	X	
Optical Motion Detector				X	
Optical Density Comparator				X	
Macroimaging (Television)	X				JPL (Mariner)
Macroimaging (Facsimile)		X	X		Aeronutronic
Infrared Radiometer	X	X			JPL (Mariner)
pH Meter		X			
Ba $(OH)_2$ Conductivity Cell			X		
β-Ionization Counter		X			
α-Scattering		X	X		JPL
Gas Solid Chromatograph		X	X		NASA Ames - JPL
Gas Liquid Chromatograph		X	X		NASA Ames - Aeronutronic
UV and Visible Spectrophotometer		X	X		
Infrared Spectrophotometer		X	X		
Fluorometer		X	X		
Polarimeter			X	X	
Mass Spectrometer		X	X		Consolidated Systems Corp
Weight Scale			X		
Soil Probe				X	

5.4 REPRESENTATIVE ALTERNATIVE EXPERIMENTAL CAPABILITY

5.4.1 GENERAL

As previously indicated, the instrumentation complement selected for the design point ABL can perform a considerably greater number of experiments than those used to define the instrument complement. In fact any experiment employing the same, or even similar, chemical processes or procedures, and the same analytical end-instruments, could be conducted, and, with the inclusion of appropriate chemical reagents and other consumables in the laboratory, almost any experiment becomes feasible. It is for this reason that the statement can be made that the resulting instrument complement is representative of a sufficiently complex experimental capability that most probable engineering problems associated with this class of payload are revealed.

The number of possible alternative experiments being very large, no attempt was made to identify specific alternative experimental procedures in detail as was done for the complement initially selected and defined in Paragraph 5.1. An attempt has been made, however, to indicate the general classes of experiments which can be performed, and these are identified in Paragraph 5.4.2 which follows. This listing should not be considered exhaustive. Also, no attempt has been made to indicate relative value of any listed experiment classes for biological planetary missions. They are indicative, however, of the very extensive analytical capability inherent in the basic design point ABL.

5.4.2 ALTERNATIVE EXPERIMENTAL CAPABILITY

a. Chemical and Physiological Nature of Life Forms Detected

(1) Macrostructure and Movement

(a) Form
(b) Size
(c) Color
(d) Texture
(e) Rate of movement
(f) Nature of motion

(2) Chemical Composition

(a) Elemental analysis (especially carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur).

(b) Identification of functional groups.

(c) Separation and identification of groups of organic compounds.

(d) Identification of specific organic compounds:

- Monomeric units of molecular aggregates
- Pigments

(3) Dynamic Functions

(a) Metabolism (pure culture)

- Rate of substrate utilization as a function of

(1) Substrate provided
(2) Temperature
(3) Atmospheric composition and pressure
(4) pH
(5) Osmotic pressure
(6) Inorganic ions
(7) Inhibitors added
(8) Optical configuration

- End products accumulated as a function of

(1) Substrate provided
(2) Oxygen pressure (aerobic versus anaerobic)
(3) Inhibitors added
(4) Optical configuration

(b) Photoresponses

- Photosynthesis
- Rate as a function of

(1) Light intensity
(2) Light quality
(3) CO_2 and O_2 partial pressure
(4) Use of specific inhibitors
(5) Element and inorganic ions available
(6) Degree of dehydration

- Products

(1) Solids
(2) Gases

- Phototropisms

(1) Growth
(2) Movement

- Photoperiodisms

(1) Reproduction rhythms
(2) Growth rhythms
(3) Metabolic rhythms

(c) Growth, reproduction, and replication

- Increase in size accompanied by differentiation.
- Exchange of cellular material.
- Do materials replicate independently and at random time?
- Are there repeatable sequences for replication?
- Effect of environmental changes.

(d) Irritability

- Nature of response (e.g., attraction or repulsion)
- Rate of response to physical and chemical stimuli

b. The Commonality of the Origin of Martian and Terrestrial Life. The purpose of this objective is to obtain information on whether terrestrial life is a universal form of life or merely one of a spectrum. Information which will bear on this problem can best be obtained by a detailed examination of the life form by the same type of methods indicated under Part a, above.

c. Establishment of the Evolutionary Pathway of Martian Life. This objective will require an extensive classification of Martial life forms, both fossil and current. Such classification can best be accomplished by the methods of comparative morphology and biochemistry. Applicable methods are included under Parts a above, and f, follow.

d. Interaction of Life Forms with the Environment. Information relative to this objective can be obtained by comparing the environment and life forms found in one area of the planet to those observed in a different area. By cataloging such information, one can then make correlations between the nature of the life forms found and the various environmental parameters. Conversely, a specific life form can be introduced into an artificial environment and its effect on the environment determined. Thus, it is necessary to:

(1) Characterize the life form by the methods indicated in Part a.

(2) Determine the environmental parameters given in Part e plus examination of the chemical and mechanical properties of the soil.

e. Absence of Life Forms. The absence of life forms can best be explained by an analysis of the environmental history of the planet and the state-of-carbon chemistry. To ascertain these factors it is necessary to:

(1) Examine the chemical nature of the surface and subsurface.

(a) Quantitative elemental analysis.

(b) Analyses for carbon based substances.

(2) Determine environmental parameters

(a) Daily and seasonal variations in the temperature of the lower atmosphere, soil surface, and immediate soil subsurface.

(b) Spectral distribution and intensity of radiation at the planetary surface.

(c) Water content of atmosphere, surface soil, and subsurface soil.

(d) Chemical composition of lower atmosphere.

(e) Ionizing radiation levels and energies.

f. Examination for Fossile Life Forms.

(1) Visual

(a) Examination of strata for impressions, casts, compressions, and petrifactions.

(b) Macroscopic examination of fossil remains.

(2) Application of radioisotope dating methods.

(3) Examination for resistant organic chemicals.